UNIVERSITY OF CAPE COAST

EXPLORATION OF SENIOR HIGH SCHOOL BIOLOGY STUDENTS' CONCEPTUAL UNDERSTANDING OF GENETICS

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BY

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DECLARATION

Candidate's Declaration

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

Candidates Signature ………………………….. Date ………………….

Name: Abigail Fiona Dzidzinyo

Supervisors' Declaration

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

Principal Supervisor's Signature ……………………… Date ……………......

Name: Prof. Joseph Ghartey Ampiah

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ABSTRACT

There are current concerns about genetically modified organisms, DNA fingerprinting, and cloning, all of which hinge on understanding genetics. Therefore, much attention has been given to research into the teaching and learning of genetics as it is a predominantly challenging topic for both teachers and students. This study used the triangulation convergence mixed methods design to explore Ghanaian SHS elective biology students' conceptual understanding of *chromosome*, *DNA* and *gene* and to further develop and field test an instructional strategy to address students' alternative conceptions and conceptual difficulties. A multistage sampling technique was used to select 96 SHS 3, 14 SHS2 elective biology students and 20 elective biology teachers. Three instruments, namely, achievement test, questionnaire and interviews were used to collect data. The data were analysed using percentages, charts, means, standard deviations, and themes. It was found that students had alternative conceptions (mainly in the categories of preconceived notions, factual misconceptions and conceptual misunderstandings) and other conceptual difficulties in learning the three basic genetics concepts. The use of conceptual change approach (Orientation-Discovery-Restructuring) helped students overcome their alternative conceptions and other conceptual difficulties. It was therefore, recommended that Biology teachers should use the conceptual change approach in teaching genetics.

KEY WORDS

Alternative conceptions

Genetics

Conceptual development

Conceptual difficulty

Chromosome

DNA

Gene

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DEDICATION

To my dear husband, Samuel, and children, Elkanah, Keren, Jamin and Samuella, with much love

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CHAPTER ONE

INTRODUCTION

Explanation of what the problem under investigation is and the reason for studying it has been dealt with in this chapter. The chapter gives a background to the study, assesses the problem investigated, outlines the purpose of the study, and indicates the research questions that guided the study. It further points out the significance of the study, specifies how the study was delimited, as well as the limitations of the study and how they were addressed. Finally, the terms used throughout the study are defined in this chapter, in addition to a summary of how the rest of the study has been organized.

Background to the Study

Difficulties students face in learning biology concepts have been given much research attention by various studies in the last three decades which have come out with many findings. For instance, Johnstone and Mahmoud (1980) in their eight-year study of Scottish students, found that water transport in plants, and genetics were among the most difficult biology topics to be learned by secondary school students. Finley, Stewart and Yarroch's (1982) study conducted in the USA at the secondary school level, showed that cellular respiration, protein synthesis, photosynthesis, Mendelian genetics, mitosis and meiosis, are important but difficult topics for students to learn. Other topics found to be difficult for students were respiration and photosynthesis (Anderson, Sheldon & Dubay, 1990), gaseous exchange (Seymour & Longdon, 1991), as well as the concept of energy (Jennison & Reiss, 1991). Lazarowitz and Penso (1992), identified Israeli high school students' learning difficulties in biology concepts as including cells, organelles, organs and their physiological processes, hormonal regulation, oxygen transport, controlled experiments and the principle of structure and function. Bahar, Johnstone and HanselI (1999), found that monohybrid and dihybrid crosses and linkages, genetic engineering, meiosis, central nervous system, gametes, allelemorphs and genes were considered to be difficult by Scottish students. Hickey, Kindfield, Horwitz and Christie’s (2003) study on how to integrate curriculum, instruction, assessment and evaluation also stressed the point that genetics was a predominantly challenging topic for science teachers. Thus, it can be said that an appreciable number of the literature on difficult topics in biology for both teachers and students, makes mention of genetics or concepts within genetics as among the problem areas.

This problem needs to be addressed as currently genetics, particularly modern molecular genetics, is crucial to the teaching, learning as well as research in the biomedical sciences (Treagust, 2006). Additionally, the ability to come to terms with modern day concerns associated with genetically modified organisms or foods (GMOs), DNA fingerprinting, gene therapy, genomics and cloning cannot be achieved without understanding genetics. Indeed, for the general populace to understand such issues, relevant genetics education must be pursued in schools. However, to date research at the international level makes it clear that genetics and genetics technologies’ students have poor understanding of concepts in the area, with rampant alternative conceptions (Bahar, Johnstone, & Hansell, 1999; Donovan & Venville, 2012; Venville & Treagust, 1998). It is worthy of note that the problem is not limited to just a few countries, but rather to several, both developed and developing. The situation is not much different in Ghana.

In Ghana, teachers of any subject at the senior high school are expected to consult the national syllabus and government approved textbooks to help them prepare students for the West African Senior Secondary Certificate Examinations (WASSCE). Biology teachers are also supposed to use the biology syllabus and the recommended textbooks in their teaching. A close look at the biology content studied at the junior and senior high schools and the university reveals that genetics is studied into increasing details/abstraction from the junior and senior high schools to the university level. However, at the junior high school, students are merely introduced to the concept of heredity, where they are only expected to be able to explain the term heredity, and mention some traits that children inherit from their parents (MOE, 2012). This is supposed to serve as a basic foundation for genetics education at the SHS. According to the objectives and evaluation outlined in the national syllabus for integrated science at the JHS level, genetics is taught to enable students explain why offspring resemble their parents (Ministry of Education [MOE], 2012). In addition, the syllabus for SHS integrated science (which is compulsory for all students at that level), also involves aspects of genetics. Yet it is not as detailed as that in the elective biology. Nonetheless what is offered in the integrated science syllabus can be used as a foundation for genetics in the elective biology syllabus.

The Section 5, Unit 1 of the SHS 3 part of the integrated science syllabus which is on variation and inheritance (concepts in genetics) is premised on the objectives that students will be able to (i) relate nucleus, chromosomes and genes as a sequence in inheritance, (ii) explain the causes and consequences of variation, (iii) explain how sex is determined in humans, (iv) discuss the importance of the various blood groups and Rh-factor and outline their importance, and (v) explain how the sickle cell gene is inherited and how the disease is acquired (MOE, 2012) after going through the Unit. To be able to meet these objectives, the students are required to be conversant with the cell, its components and functions as the relevant prior knowledge.

However, genetics in the elective biology syllabus is much more detailed. It involves knowledge of some basic terms in genetics, chromosomes as the basis of genetics, the concept of inheritance, Mendel's first and second laws of inheritance, types of hybrids, gene interactions, variation – causes and consequences, continuous and discontinuous variations, heritable and non-heritable variations, in addition to many other concepts. The syllabus makes it clear what is required of students after going through each unit of a section. For instance, the 2010 edition of the elective biology syllabus, year three section two, has two units (5 and 6) dealing with genetics. Some of the requirements are that students be able to explain terms, state laws and distinguish between different types of variation after going through each of the sub-units. Thirteen sub-units, fourteen of the objectives require that students be able to explain some concepts after having been exposed to such, and only two require that students distinguish between different forms of variation and inheritance (MOE, 2012).

It must be pointed out that syllabuses in different countries the world over have undergone various changes over the years. The Ghanaian biology syllabus has not been an exemption. It has been revised over the years with attendant changes made where appropriate. In the area of genetics, a noteworthy change made in the syllabus can be seen in the sequencing of the content of the 2008 and 2010 revisions. In the 2008 revision, ‘Cell Biology’ - Nucleic acids, DNA Structure and replication and RNA transcription, Protein Synthesis, Cell cycle – is treated in the second year, section four while ‘Genetics’ – Heredity, Variation and Population Genetics – is considered in the third year, section three. This arrangement is not the best, since the break in continuity may make it difficult for students to be able to link the two major concepts. This is a problem as understanding genetics is heavily hinged on grasping concepts in ‘Cell Biology’. On the other hand, in the 2010 revision of the syllabus, there was a change in the ordering of the content of the two main concepts which addressed that problem. In it ‘Cell Biology’ and ‘Genetics’ are both treated in the same year and the same section (that is, third year, section two) with ‘Cell Biology’ directly preceding ‘Genetics’. This is most appropriate, as the students can readily link the associated concepts and thus better conceptualize the main ideas in ‘Genetics’.

To be able to achieve the objectives outlined in the syllabus, and for students to truly conceptualise the concepts in genetics, the appropriate textbooks must be used by teachers and recommended to students for their personal reading on the subject. At the senior high school, the main textbook that has been approved for teaching and learning biology is *Biology for Senior Secondary Schools* (Nyavor & Seddoh, 1991). The approval has been since the inception of the new educational reforms in 1987 to date. Considering the fact that the first batch of senior high school students entered the secondary school in the 1990/1991 academic year, it means this particular textbook has been in use for twenty-six years running. The approval for its usage is given by both GAST (Ghana Association of Science Teachers) and the Ministry of Education. In this textbook, genetics and evolution are treated in the sixteenth and last chapter. It is far removed from the chapters that treat DNA and protein synthesis, and Cell division – The Cell 2 (in the textbook). It would have been most appropriate if the Cell 2 chapter had directly preceded the 'Genetics and Evolution' chapter. The reason being that it would have augured well for continuity of concepts, and thus helped in students' conceptual development in genetics. The 'Genetics' chapter begins with learning objectives, followed by background information. The background information consists of a list of terms used in genetics that have been defined. This is followed by a brief explanation of the concept of chromosomes. An activity to help students get a concrete picture of chromosomes follows the explanation. The concept of inheritance is explained using Gregor Mendel's experiments. Figures giving a visual impression of monohybrid inheritance are presented alongside the explanations given. This is the format used throughout the chapter: concepts are explained with figures interspersed where appropriate. For some of the concepts, to aid understanding, activities have been designed to help students investigate and find out some of the ideas first hand. Some of the activities are practical, requiring students to work with real objects, especially plants. This is quite laudable as it helps make the subject less theoretical. For instance, 'Activity 16.2: Investigating monohybrid inheritance', requires students to select and sow viable cowpea seeds of two different colours, and follow given instructions to come up with the ratios of the F_1 and F_2 generations of the crosses investigated (Nyavor & Seddoh, 1991).

However, a number of the sub-concepts have been explained without figures and attendant activities. These include: genetic engineering, artificial selection, hereditary and environmental variation, and natural selection. Throughout the chapter, only one coloured picture (of the peppered moth, *Biston betularia*) depicting an example of natural selection is used. This leaves much to be desired as the inclusion of more coloured pictures would help students' conceptual development. When conditions discussed are given pictorial representations in real life, it aids students understanding of concepts presented.

It must be emphasised that most of the content has been presented briefly. This is a source of concern as the textbook is the main one highly recommended for senior high schools. Enough and relevant content must be included to ensure students have a well-rounded understanding of concepts in the area of genetics. Detailed examples of real life expression of conditions or disorders as a result of heredity or variation are not included in the exposition. In addition, self-check questions for pupils to try their hands on after going through sub-concepts in the text are completely missing. Of course, there are 15 self-check questions at the end of the whole chapter. But this is not enough. In the development of the chapter, self-check questions after each sub-concept would have been most welcome. This is because it will afford students a chance of assessing themselves across all the concepts, and when necessary immediately go back to revisit concepts not well understood before proceeding to subsequent ones. This should be in addition to the final overall chapter self-check.

However, the GAST textbook is not the only one used by teachers. Other books such as *Life* (Lewis, 1998), *Fast-Track Approach to Biology* (Ashitey, 2008), as well as various 'handouts' are also used. In *Life*, genetics has been treated differently from the GAST textbook. The content of the book has been planned such that the units dealing with 'Cell biology and Reproduction' and 'Development' directly precede genetics. This is most appropriate, since concepts in the two units complement concepts in genetics. The unit on genetics is divided into four chapters as 'Transmission Genetics', 'Chromosomes', 'DNA Structure and Replication', and 'Gene Function'. The first chapter begins with genetics' history. Here evidence of the awareness of heredity in ancient civilizations is given in addition to Gregor Mendel's investigations into transmission of traits from parents to offspring (Lewis, 1998). Next Mendel's first law is explained and his experiments outlined. This is followed with other concepts. These concepts are explained into much detail. Coloured pictures and photographs as well as self-explanatory diagrams are used throughout this chapter and the remaining three.

After going through a number of sub-concepts, questions, usually three to five in number, are provided for the student to do a self-check. These questions are captioned 'Mastering Concepts'. They are not simple recall questions (that is of low cognitive order on Blooms taxonomy). Rather, they range from low (recall/knowledge) to complex (synthesis/evaluation) cognitive levels of educational activity. For instance, the self-check under the exposition on Mendel's first law includes the questions: 1. How did Mendel's experiment reveal how single genes are transmitted? 2. How do Mendel's observations reflect events of meiosis? 4. Distinguish between a heterozygote and homozygote; phenotype and genotype; dominant and recessive; wild type and mutant." The first question requires the student to explain and summarize information provided in the section. Thus it is of the knowledge and comprehension orders. The second can be answered if the student is able to relate Mendel's observations to the concept of meiosis, information that is not directly provided in the text. Thus calling for application of concepts. Question 4 (the third in the example cited), calls on students to scrutinize information given to come up with differences noted – an analysis question. Obviously such self-check exercises are included to help students undertake a self-assessment exercise to be able to ascertain whether concepts explained in the text have been grasped or not. This type of assessment is laudable as learners are in this way aided to be sure they have mastered a particular concept before proceeding to the next. This is especially necessary when the understanding of succeeding concepts are dependent on understanding of preceding ones. In that vein, it will also be beneficial to students if they try their hands on WASSCE past questions after having been taught the relevant concepts.

The layout and content of *Excellent Biology for Senior High Schools* are almost the same as that in the *Biology for Senior Secondary Schools*. In it too, 'Genetics' is treated far apart from 'The Cell'. The content is not detailed. Information presented, though concise, leaves one with the impression that much more details would have sufficed. However, it includes some self-check questions for some concepts. For example, under the concept sex-linked inheritance in humans, the questions for self-check are "Why is the occurrence of sex-linked characters a more common feature in males? Why is the occurrence of sex-linked characters a less common feature in females?" It can be seen that the second question is redundant, since it can be inferred from the first one. It must be emphasized that both *Biology for Secondary Schools* and

Excellent Biology for Senior High Schools, textbooks highly recommended for senior high school biology and written by Ghanaian authors, appear to have been put together in an ad hoc manner. (This is with regard to the presentation of genetics only). On the other hand, *Life*, written by a foreign author, presents genetics in a better way.

Since students are prepared in the classroom to write WASSCE, the nature of the questions set over the past years need to be examined. The SSSCE/WASSCE genetics questions for the years 1993, 1997, 1998, 1999, 2004, 2007, 2008, 2011, 2012, 2013, 2014, 2015, 2016, 2017 and 2018 were scrutinized. The scrutiny revealed that generally the emphasis of the questions is on candidates' ability to define terms and apply concepts in answering hypothetical, but practical genetic inheritance problems using genetic diagrams. All the genetics questions for the fifteen years followed the format of that for the 2015 which is as follows: '(a) Explain the following: (i) test cross (ii) monohybrid (b) In a mango plant, the allele for bean-shaped seed is r and is recessive to round-shaped seed R. With the aid of a genetic diagram, determine the genotypes of the offspring if: (i) a homozygous bean-shaped parent is crossed with a homozygous round shaped parent; (ii) both parents in (b)(i) are heterozygous' (WAEC, 2015). It may seem that since the format has been consistent over the years, students may have been taught to be able to tackle such questions appropriately. However, per the WAEC chief examiners' reports, candidates are not able to perform as expected. Apparently students are not grasping the concepts as they should to be able to answer the questions on the examinations.

Since students are not able to perform well on the examination, it appears there is something in the syllabus, textbooks and examination questions that they find daunting. There is thus the need to ascertain what is hampering their smooth learning and tackling of genetics questions during the terminal examination for the senior high school. The WAEC chief examiners' report may provide insight into what students find problematic with the content of the genetics taught at the senior high school.

At the senior high school level of Ghana's education system, teaching and learning of genetics is quite challenging and difficult. Indeed from personal experience both as a student and a teacher, I can say with much confidence that students find concepts in genetics difficult to conceptualize. This may be because the teachers who teach the subject also find it challenging to teach for students to gain 'deep understanding' of the concepts. In addition, interaction with teachers who are currently teaching senior high school biology has made it clear that genetics is actually a thorn in the flesh for most teachers. The students too, according to the teachers, do not prefer genetics questions on examinations. One teacher in a one-on-on discussion, asserted that if there are other options to answering genetics questions, students usually selected those instead; where they are forced to answer the questions on genetics, they tend to give only 'surface' or shallow information.

In a nutshell, according to teachers on the ground, teachers find it hard to teach learners to be able to make connections between interrelated genetics concepts. In such a situation, the students can be said to have only superficial understanding (Zirbel, 2006). However, there is yet another line of evidence indicating that Ghanaian senior high school students and teachers find genetics tough – the former to learn, and the latter to teach – the West African Examinations Council (WAEC) chief examiners' reports.

For five consecutive years WAEC chief examiners' reports have made it clear that most students do not choose to answer genetics questions (WAEC 2008, 2009, 2011, 2012, 2013). Consider the chief examiners' report on question 4 of the May/June, 2011 paper 2, which was a genetics one. The question was as follows: "4. (a) Explain the following terms: (i) diploid; (ii) polygenic inheritance. (b) (i) Explain the differences between *sex linkage* and *autosomal linkage*. (ii) Give two examples of a sex-linked character. (c) Mr. John who does not have the sickle-cell anaemia trait is married to Mary who is a sickler; yet he claims the sickler child born to them is not his child. Determine by the aid of a genetic diagram whether his claim is true or false." The question required that candidates give a clear and detailed account of the two terms, 'diploid' and 'polygenic inheritance'. Furthermore candidates had to differentiate between the terms *sex linkage* and *autosomal linkage*, with examples. In addition, candidates were required to use a genetic diagram, in which the genotype and gametes of the parents will be clearly indicated and crossed to give the F_1 generation's genotypes; and the phenotypic expressions would have to be shown as well. The chief examiners' report on candidates' performance on the question indicated that they found it challenging. According to the chief examiners the question was avoided by most candidates, but the few who attempted it rather performed fairly well. Candidates gave correct examples of sex-linked characters as haemophilia, colour blindness and baldness. Most of the few candidates who attempted the question, were able to deduce the genotypes of Mr. John who does not have the sickle-cell anaemia trait as AA, and Mary, who is a sickler as SS, and further constructed the genetic diagram correctly in part (c). However, the candidates could not "adequately explain the biological terminologies" (WAEC, 2011, p.187).

The 2009 May/June Biology 2 detailed chief examiners' comments on the genetics question was in a similar vein. The question was: "4. (a) Explain the following terms: (i) artificial selection; (ii) outbreeding; (iii) inbreeding. (b) State two advantages and two disadvantages each of (i) outbreeding; (ii) inbreeding (c) Explain briefly what will happen in a blood transfusion if the blood of the two individuals are compatible." The report has it that it was the least attempted question. Also the few candidates who attempted the question performed poorly. In part (a), according to the chief examiners, the candidates showed complete lack of knowledge and some took it as a question on natural selection. The question required candidates to explain that artificial selection involves the application of the knowledge of genetics by farmers or animal rearers, crop or animal breeders by special methods to produce organisms or offspring with desirable characteristics or traits. Yet, candidates appeared to lack this understanding of the concept.

In addition, the report had it that candidates showed some knowledge regarding part (b). However, some of the candidates messed up the advantages and disadvantages of outbreeding and inbreeding. Candidates were expected to state the advantages of outbreeding as resulting in variation, hybrid vigour and production of healthier, more resistant and early maturing offspring of species. However, the disadvantages of outbreeding include the possible loss of some desirable characters of the parents and the introduction of some new undesirable characters of parents.

With regards to the advantages of inbreeding, candidates should have stated that the practice enhances the maintenance and buildup of traits within the stock. Also, the offspring show no variation from their parent stock. The disadvantages should have included: the loss of productive vigour later in the stock, offspring exhibiting increased susceptibility to diseases, and it giving rise to homozygous recessives. Furthermore, the report had it that "all the candidates who attempted part (c) showed absolute lack of knowledge as to what will happen in a blood transfusion if the blood of the two individuals are not compatible" (WAEC, 2009, pp. 26-27).

One may say that the May/June 2012 question on genetics was better answered than the aforementioned considering what the chief examiners reported. Yet, candidates had problems with the definition of terms part. The question was: '4. (a). Define the following terms giving one example in each case: (i) Co-dominance; (ii) sex-linked characters; (iii) Genetic engineering; (b). A man who does not carry the haemophilia gene marries a woman who is a carrier of haemophilia. With the aid of genetic diagram, determine the probability of their offspring having the disease' (WAEC, 2012). The question (a) required candidates to state or describe the given terms in exact language. Candidates could not give the appropriate description as indicated in the chief examiner's detailed comments: "Many of the candidates could not define the terms co-dominance, sex-linked characters, and genetic engineering" (WAEC, 2012, p.210). On the other hand, question (b) required candidates to use a genetic diagram to determine the probability of the offspring having haemophilia disease. This, per the chief examiners, was well answered by most candidates (WAEC, 2012).

Generally, candidates who sat the 2008 paper reportedly performed well on the genetics question. Yet, some of them still had problems with the genetics question. Consider the question and the chief examiners' report: "3. (a) (i) What is monohybrid cross? (ii) If the recessive gene responsible for skin colour in albinism in humans is represented by *a*, what are the possible genotypes and phenotypes of offspring produced by a homozygous normal man and a heterozygous albino woman? (b) (i) Explain how the sex of a human baby is determined. (ii) Name two sex-linked characters" (WAEC, 2008). The chief examiners reported that many candidates attempted the question and performed well. However, others also failed the question "abysmally" because according to the report, they exhibited confused knowledge of the question (WAEC).

As evident in all the comments enumerated, all is not well for our senior high school biology students when it comes to genetics. Indeed, with candidates avoiding genetics questions, the few attempting the questions failing "abysmally", candidates exhibiting confused knowledge of concepts examined, as well as candidates' inability to clearly define the terms used in genetics, it can be surmised that there is a problem with Ghana's senior high students' conceptualization of genetics concepts. Thus, one cannot help but agree with what the literature reports that mastery of the genetics content and reasoning goals defined in current science education standards (Hickey et al, 2003) are found to be a daunting task by students. If students are exhibiting confused knowledge or failing in genetics, then it will not be farfetched to conclude that students are having conceptualisation problems in their study of genetics. In order to ascertain the source of the problem, a number of issues have to be considered. Issues such as Ghanaian students' alternative conceptions of genetics, how Ghanaian teachers on the field are currently teaching genetics vis-à-vis what is stipulated in the syllabus, as well as what is being done wrongly and rightly with the teaching and learning of genetics.

Alternative conceptions in the sciences in general, and biology in particular, have gained much attention in the literature (Hestenes, 2006; Hewson, 1992; Weiler, 1998; Zirbel, 2006). Alternative conceptions are considered as the foremost factor impeding students' learning, achievement and conceptual development in science (Aldahmash & Alshaya, 2012). In biology, students' alternative conceptions in genetics have been reported on by several researchers (Donovan & Venville, 2005; Lestz, 2008; Lewis, Leach & Wood-Robinson, 2000; Venville & Donovan, 2007; Venville & Donovan, 2005; Venville, Grible & Donovan, 2005). The following alternative conceptions of students in genetics were garnered from the literature:

Genes and DNA are separate things – According to Venville and Donovan (2007), many students think of genes and DNA as discrete things. From their study, they found out that some students had the idea that genes are what make you look like your family and DNA is for identification. According to them, the focus on DNA in solving crime in the media contributes to this view. Such students must be helped to understand that a gene is a segment of a DNA molecule.

Genes are only found in certain cells – Some students tend to have the view that genes are only found in certain cells, such as blood cells, brain or reproductive system. It is important for them to understand that, except for mature red blood cells, all human cells contain DNA and therefore genes (University of Waikato, 2007-2011).

Different cells contain different genes – Donovan and Venville (2005) in their study about teaching the complexity of the gene with clarity, found that students often think that different cells contain different DNA. For instance, some students think the DNA in their skin cells is different from the DNA in their heart cells (Donovan & Venville, 2005). But the fact is that every cell in the body, except the gametes, contains the same DNA and consequently the same genes. However, not every gene is expressed in every cell. For example, the genes that code for muscle proteins such as actin and myosin are only expressed in muscle cells and not in the other cells of the body, though the genes are present in those other cells (University of Waikato, 2007-2011).

We are all unique because we have different genes (Lewis, Leach and Wood-Robinson, 2000) - Students may think we are all unique because we each have different genes (University of Waikato, 2007-2011). However, all humans have almost exactly the same genes, in the same order, along our chromosomes. Our uniqueness is a result of the different combinations of alleles that we inherit from our parents. This difference in the combination of alleles results in a unique combination of traits.

Genes code directly for our traits – Venville and Donovan (2005) assert that students commonly think of genes as direct instructions for particular traits. However, genes code for proteins that make up our cells, tissues and organs, ultimately leading to our unique phenotypes.

Single genes code for particular traits – This alternative conception, has been attributed to examples used when teaching about genetics (Venville, Gribble & Donovan, 2005). If the relevant examples are not cited, some students may be led to the view that particular traits are always coded for by a single gene. While there are a few traits that are determined by a single gene (for example, dimples), most traits are complex and are the result of the interactions between several genes.

We only have genes for the traits that are displayed - Students might think that we only have genes for the traits we display (Venville & Donovan, 2005). In fact, for diploid organisms, at any given locus there are two alleles (alternative forms of the same gene). Different alleles of a gene generally serve the same function but may produce different phenotypes depending on which set of 2 alleles you have and whether 1 allele is dominant.

Inheritance involves an averaging of the genes from both parents - Some students view genetic inheritance as an averaging of the genes from both parents (Donovan & Venville, 2005). For example, 1 short parent and 1 tall parent will result in a child of average height. However, our characteristics (such as height) are commonly controlled by a number of genes. A child's genotype is a unique combination of genes from both parents and is not merely a blending of the two. In addition, dominance means that a child may display characteristics of only 1 parent.

If Ghanaian high school students are having these and other alternative conceptions, it will be quite difficult for them to form the authentic scientific meanings of these concepts. Thus teachers would have to address these in their instruction to ensure learners replace these with the authentic ones through assimilation and accommodation.

Statement of the Problem

Contemporary issues such as genetic modifications/manipulation, DNA finger-printing, genomics and cloning, which have become hot debate topics globally, can best be understood with adequate background knowledge in genetics (Banet & Ayuso, 2000). Also, learning and research studies in the modern biomedical sciences is basically hinged on the study of genetics (Treagust, 2006). Furthermore, the few concepts in secondary school biology which call for reasoning and problem solving include genetics' concepts (Stewart & Hafner, as cited in Tsui & Treagust, 2006). This makes genetics an important topic to be studied at all levels of education, including high school. However, researchers over the past three decades have found that genetics remains conceptually and linguistically difficult to teach and learn in high schools (Bahar, Johnstone, & Hansell, 1999; Hackling & Treagust, 1984; Johnstone & Mahmoud, 1980; Pearson & Hughes, 1988; Venville & Treagust, 1998).

As it is a problem area for both learners and teachers, several studies have been undertaken to ascertain the source or causes of the difficulties. Several reasons have thus been advanced for the persistence of the problem. Five major difficulties have been identified in the literature on genetics education. Knippels (2002) names these as the domain-specific vocabulary and terminology, the mathematical content of Mendelian genetics tasks, the cytological processes, the abstract nature of the subject in the biology curriculum, and the complex nature of genetics: a macro-micro problem.

These different problem areas are not isolated and may intensify each other. For example, students face problems in representing genetics texts into schemes and symbols, and vice versa, that is, in reading schemes and symbols (Knippels, Waarlo & Boersma, 2005). Also, knowledge of the extensive genetic terminology is required to understand a classical genetics problem (Knippels, Waarlo & Boersma). This being the case, it can be said that the Ghanaian SHS elective biology curriculum has responded to some of these challenges by including an extensive genetic terminology which is also reflected in the textbooks used by students at that level. However, studies have reported that students are often not familiar with the definitions of the genetics-related terms, and they may get confused because a number of terms look and sound very similar, e.g. homologue, homologous, homozygous and homozygote (Bahar *et al*, 1999). Besides, students face problems due to misapplication of genetic terms, the existence of synonyms and the occurrence of redundant and obsolete terminology (Knippels, Waarlo & Boersma). The confusion over definition of terms as well as misapplication of the genetic terms are reported by WAEC Chief Examiners. The reports indicate that candidates do not adequately explain the genetics terminologies. Also, many of the candidates were reportedly not able to define terms such as co-dominance, sex-linked characters, genetic engineering, test cross, monohybrid cross (WAEC, 2011; 2012; 2015).

Moreover, candidates must do mathematical calculations with symbols in solving the genetic cross problems, and to connect probabilistic reasoning with biological phenomena (Knippels, Waarlo & Boersma, 2005). Yet the literature reports that students often manipulate symbols and apply algorithms without correct insight into the underlying inheritance patterns (Thomson & Stewart, cited in Knippels et al). However, the manipulation of the symbols and application of the algorithms is very pertinent to solving the hypothetical genetics problems that usually appear on WASSCE questions. Without the correct insight into the underlying inheritance patterns, the ability to solve such questions will be greatly stalled. Biology students in Ghanaian SHS have the same difficulties. WAEC Chief Examiners' reports show that candidates are not able to solve hypothetical problems presented on WASSCE genetics questions. For example, note the report on candidates' performance on the 2009 genetics question. The part of the question concerned is '(c) Explain briefly what will happen in a blood transfusion if the blood of the two individuals are not compatible." The Chief Examiners reported that "all the candidates who attempted part (c) showed absolute lack of knowledge as to what will happen in a blood transfusion if the blood of the two individuals are not compatible" (WAEC, 2009, p.26, 27). In addition, question 4 in the 2011 paper was reportedly avoided by candidates, and that the few who attempted it performed just "fairly well" (WAEC, 2011, p.20).

As a result of the above shortcomings of students, WASSCE genetics questions are said to be the least attempted questions on the biology examination (WAEC, 2009; 2011; 2016). After candidates have been taught genetics, they continue to be confused over definition of terms, avoid tackling the questions, show absolute lack of knowledge, and deviating. For instance, for the 2009 question 4. (a) Explain the following terms: (i) artificial selection; (ii) outbreeding; (iii) inbreeding", the chief examiners reported that the candidates showed complete lack of knowledge and some took it as a question on natural selection (WAEC, 2009). Yet the question only required candidates to explain that artificial selection involves the application of the knowledge of genetics by farmers or animal rearers, crop or animal breeders by special methods to produce organisms or offspring with desirable characteristics or traits. There should have been no mention of natural selection in the explanations candidates gave.

Furthermore, the genetics question in the 2018 paper was on variation. Question 4 (a) required students to state five each of the causes and consequences of variation to living things. According to the report, though the question was a popular one, “the performance was unsatisfactory” (WAEC, 2018, p. 20). On the other hand, for the 2016 paper, the genetics question (i.e. Q4) was reportedly “the least attempted and poorly answered” (WAEC, 2016, p. 16).

The structuring of biology curricula across the globe in which the topic of meiosis is isolated from heredity is said to add to the abstract character of genetics (Duncan & Reiser, 2007). This is so in the Ghanaian SHS biology curriculum as well. Some of the textbooks used by both teachers and students have also been structured such that meiosis is far removed from heredity. For instance, the GAST biology textbook – *Biology for Senior Secondary Schools*, and *Excellent Biology for Senior High Schools* both have meiosis separated from heredity. Previous syllabi such as the 2007 have the topic dealing with meiosis far removed from that dealing with heredity. Although the 2010 SHS biology syllabus has rectified the anomaly, whether teachers on the field are aware of this ‘correction’ and have adjusted their instruction, accordingly, is yet to be ascertained. Also, whether all teachers use both the syllabus and recommended textbooks in their notes preparation or not must be affirmed. Duncan and Reiser (2006) make it clear that students’ understanding of cell division processes appears to be limited, confused, and inconsistent. Also, they report that students make little distinction between mitosis and meiosis, and have poor understanding of the purposes, processes and products of cell division (Duncan & Reiser, 2006). Ghanaian SHS biology students face similar difficulties as evident in chief examiners' reports. Thus, the chief examiners report that performance on genetics questions are abysmal, low, unsatisfactory, poor (WAEC, 2008; 2009; 2012; 2018).

Also, several research findings have unearthed students' difficulties with the chromosome concept (Lewis & Wood-Robinson, 2000; Lewis *et al*, 2000a; Lewis et al 2000b). Yet most of the concepts in heredity are hinged on the chromosome concept. Students have also been reported to exhibit alternative conceptions and other conceptual difficulties with the genetics concepts DNA and genes (Kilic, Taber & Winterbottom, 2016; Lewis & Wood-Robinson, 2000; Smith & Knight, 2012), which are equally important in having a deep understanding of genetics. These difficulties may be due to the existence of alternative conceptions, since according to Aldahmash and Alsahya (2012) learning, achievement, and conceptual development are adversely affected by the presence of alternative conceptions. Also, 'authentic alternative conceptions are tenaciously held, and are doggedly resistant to change' (Wennings, 2008, p.11). Although literature report difficulties with genetics concepts such as chromosome, DNA and gene, the nature of the difficulties are not given much attention.

Most of the studies in genetics education explored and described the learning and teaching difficulties in the subject, with little attention given to the development and field-testing of instructional strategies to address the problems that have been unearthed by various research endeavours (Chattopadhyay, 2005; Donovan & Venville, 2008; Knippels, Waarlo & Boersma, 2005; Leach &Wood-Robinson, 2000; Venville & Donavan, 2007, Lewis; Knippels, Waarlo & Boersma, 2005). Also, WAEC chief examiners reports, though very detailed on students' weaknesses in genetics, are quite vague on what should be done to address the problem. For instance, the May-June, 2011 report stated that "tutors should ensure that they teach candidates acceptable definitions and explanations of biological terminologies" (WAEC, 2011, p.184). Additionally, most of the reports, though reporting weaknesses of students in answering genetics questions, make no suggestions as to how the problem could be remedied (WAEC, 2012; 2013; 2016; 2017; 2018)

Purpose of the Study

The purpose of this study was to explore the conceptual understanding of Senior High students in three basic genetics concepts – *chromosome*, *DNA*, and *gene*. Thus, the study sought to unearth the prior conceptions students bring into the genetics classroom and document them in order to be able to help them understand concepts in genetics.

This study also sought to document classroom practices of both teachers and students during genetics lessons in order to help inform both pre-service and in-service teachers on best practices to emulate and bad practices to avoid when teaching genetics to SHS students. The classroom practices of teachers that were targeted include questioning skills, feedback, distribution of questions, involvement of students in lesson, handling of students' questions/contributions, use of teaching learning resources. The focus on students' classroom practices was their participation in lessons through asking and answering questions, their handling of learning resources when required to do so, and their response to feedback given by teacher when they ask or respond to questions.

In addition, the frequency at which students use their alternative conceptions in answering genetics questions on a test/examination compared to the frequency at which they use the scientific conceptions were examined. This was intended to ascertain whether students who have been taught the scientifically accurate concepts will easily abandon their inaccurate or alternative conceptions for the scientific ones.

Finally, the various teaching techniques and strategies employed by teachers to genetics were explored. This was meant to help determine what teachers may be doing in terms of the teaching methods employed that contributes to students holding onto alternative conceptions even after having been taught genetics concepts. This was also meant to further help in finding the 'best' strategies and techniques to be used in teaching genetics for conceptual understanding.

Research Questions

The following research questions guided the study:

1. What conceptual understanding do SHS biology students hold in genetics with regards to:

   (a) chromosome,

   (b) DNA, and

   (c) gene?

2. How often do students use alternative conceptions and scientific conceptions to answer genetics questions?

3. (a) What are SHS teachers' perception of genetics?

   (b) How do SHS teachers teach genetics?

   (c) What areas do SHS teachers emphasise when teaching genetics?

4. How effective is the conceptual change approach used to help improve students' conceptual development of genetics' concepts?

Significance of the Study

The study findings may be of much importance to both pre-service and in-service biology teachers. Whereas the former will learn how best to tackle the subject right from the beginning of their career, the latter will be equipped with an approach that will enhance their competence in teaching genetics.

Students are likely to benefit as well since they will be helped to conceptualise desired genetics concepts when their teachers employ the new approach reported in this study in their teaching. In addition, students who pursue higher education in pure or applied biology that involves the application of concepts in genetics (such as biomedical science.), will be better equipped to succeed in their chosen fields. Faculty tasked with training prospective biology teachers can also get researched information from this study which could be used to augment the training they give trainee teachers on the appropriate strategies to be used in teaching genetics.

Delimitation of the Study

Genetics at the SHS covers heredity and variation, and builds up from cell biology. Among the concepts to be mastered are terms used in genetics. These include gene, chromosome, DNA, genotype, phenotype, dominant, recessive, allele, locus, test cross and back cross (MOE, 2010). This study was delimited to the *chromosome*, *DNA*, and *gene* concepts. This is because they are the core concepts that almost all of the other concepts are built upon. Also, the study focused more on SHS 3 elective biology students. This is because as outlined in the elective biology syllabus, genetics is taught in year three, at the senior high school level.

Limitations of the Study

The main limitation of this study is that at the second phase of the study where the effectiveness of the intervention was checked, a control group was not used. A single group was pre-tested and post-tested after they were taught using the intervention.

Definition of Terms

Conceptual change as used in this study refers to the process of developing basically new concepts as a result of the restructuring of aspects of ones existing conceptions through the acquisition of knowledge. The newly developed concepts are the acceptable scientific concepts.

Conceptual development in this study refers to the process by which learners' conceptual structures are enlarged such that the richness and precision of meaning of learners' frameworks are greatly enhanced.

Conceptual difficulties refer to students difficulties with understanding of concepts. These are differentiated from alternative conceptions by being hazy, unclear understanding of concepts. They are present as incomplete information or distorted ideas.

Preconceived Notions – These are popular student conceptions which are based on their everyday experiences.

Nonscientific Beliefs – These are students' conceptions which have been developed from sources other than science education. The sources of these conceptions could be religious and (or) mythological teachings.

Conceptual Misunderstandings – These refer to students' conceptions that are developed from science lessons which fail to help students confront their preconceived notions and nonscientific beliefs.

Vernacular Misconceptions – These are said to be students' conceptions of scientific words which have other meanings in everyday life.

Factual Misconceptions – These refer to students' conceptions developed from false ideas that were learned in early ages but have not been challenged till adulthood.

Organisation of the Study

The rest of the study consists of four main chapters. These are the literature review (which is covered in chapter two), the study methodology (chapter three), the results and discussion (chapter four) and the summary, conclusions and recommendations (chapter five).

The literature review, Chapter Two, critically considered relevant literature that has a bearing on the current study. The topics covered include Students' alternative conceptions of, and learning difficulties with the concepts gene, DNA and chromosome; viewpoints on conceptual development and change, and methods of teaching concepts in genetics, Some perspectives on conceptual development and change, Broad perspectives, Cognitive conflict technique, Bridging analogy technique, Some complications with students' conceptual development and change, and Some teaching approaches to concepts in genetics.

Chapter Three discusses the research methodology of the study. It gives a description of the type of study and design in detail, as well as the rationale for the design. Issues relating to population, sample and sampling procedure, instruments, data collection procedure, and data analysis are also discussed in detail.

The results of the study are presented and discussed in Chapter Four. The Discussion was done according to the research questions that guided the study. The findings from the study were evaluated and their implications examined with respect to the current theoretical position on the issues as well as their practical implications.

Chapter Five gives an overview of the research problem and methodology. It further provides a summary of the key findings and their interpretations. Conclusions are drawn based on the findings; the implications relating to the findings are also discussed. In addition, recommendations as well as suggestions for further research are made.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

This present chapter is an exposition of the relevant literature that was consulted during the research. It covers both theoretical and empirical work done by science education experts on students' conceptual development, difficulties students have with the study of genetics, genetics concepts students have difficulties learning, using conceptual development approach in teaching, as well as students conceptions of genes, chromosomes and DNA. However, first and foremost, the chapter begins with an explanation of the theoretical framework/conceptual base for the study.

Literature was reviewed based on topics in order to reflect the current issues with regard to students' understanding of scientific concepts. Currently, students' understanding is hinged on constructivism and other related philosophies. Thus, reviewing literature along the following lines proved to be quite beneficial with regard to the current study. The review was done under two main themes: Students' alternative conceptions of, and learning difficulties with the concepts gene, DNA and chromosome; and viewpoints on conceptual development and change, and methods of teaching concepts in genetics. Under each of these themes sub-themes were considered.

Sub-themes considered under students' alternative conceptions of, and learning difficulties with the concepts gene, DNA and chromosome were: Constructivist views of learning, Vocabulary for labelling students' ideas, Students' alternative conceptions of gene, DNA, and chromosome, Alternative conceptions in genetics.

Under the theme 'viewpoints on conceptual development and change, and methods of teaching concepts in genetics', sub-themes reviewed were: Some perspectives on conceptual development and change, Broad perspectives, Cognitive conflict technique, Bridging analogy technique, Some complications with students' conceptual development and change, and Some teaching approaches to concepts in genetics.

Theoretical Framework/Conceptual Base of the Study

Constructivism is the theoretical framework upon which this study was based. This is not farfetched as the study is about students' thinking and learning. Indeed most research into students' thinking and learning is based on the constructivist learning views (Mutumucuio, 1998). There are several proponents of the constructivist theory. Notable among them are Jean Piaget, Jerome Bruner, Lev Vygotsky and John Dewey. Jean Piaget being recognized as the father of constructivism, since according to von Glasersfeld (1990), he was "the great pioneer of the constructivist theory of knowing".

Crucial to constructivism is the nature of human knowing, especially the nature of scientific knowledge, in addition to views of learning processes and procedures for validating acquired knowledge. Constructivism thus acts as a potent theoretical resource for maximising student learning (Educational Broadcasting Corporation, 2004).

Constructivism is essentially a theory that is based on observation and scientific study concerning the nature of learning. It articulates that people create their own understanding and knowledge of the world, as they experience things and reflect on those experiences (Woolfolk, 2016). When one chances upon something new, he/she has to resolve it with his/her previous ideas and experience, either by changing his/her beliefs, or completely discarding the new information as irrelevant (Educational Broadcasting Corporation, 2004). Whatever the case may be, the individual is an active creator of his/her own knowledge. As such, one must of utmost importance, pose questions, actively search for knowledge, and gauge what he/she knows constantly. When these steps are taken, then there is the belief that the individual learner will actually understand and be able to digest appropriately what he/she knows to enable him/her confidently acknowledge he knows (Educational Broadcasting Corporation).

In the classroom, the constructivist view of learning could be relied on in the selection of a number of different teaching practices. In the most general sense, it usually means encouraging students to use active techniques (experiments, real-world problem solving) to create more knowledge and then to reflect on and talk about what they are doing and how their understanding is changing. The teacher makes sure s/he understands the students' preexisting conceptions, and guides the activity to address them and then build on them (Educational Broadcasting Corporation, 2004; Woolfolk, 2016).

Teachers who ascribe to constructivism encourage their students to constantly assess how the activity is helping them gain understanding. The students in the constructivist classroom do this by questioning themselves and their strategies, thereby becoming "expert learners in the course of time." They thus gain ever-broadening tools to keep learning. Thus, in a well-planned classroom environment, the students learn how to learn (Educational Broadcasting Corporation, 2004; Woolfolk, 2016).

When students continue to reflect on their experiences, they find that their ideas increase in complexity and powerfulness, and their abilities to integrate new information become stronger with time (Educational Broadcasting Corporation, 2004). In the light of this, every teacher should be made to understand that it is one of a teacher's key roles to encourage learning the constructivist's way and in addition, harp on the reflection process to his/her students. By so doing, students will be helped to learn meaningfully, which may lead to the elimination of alternative conceptions (Woolfolk, 2016).

According to Educational Broadcasting Corporation (2004), unlike the criticisms made by some (conservative/traditional) educators, constructivism does not dismiss the active role of the teacher or the value of expert knowledge. Instead, it rather adapts that role, such that teachers support students in the construction of knowledge rather than the reproduction of series of facts. The teacher in this context, provides students with tools such as problem-solving and inquiry-based learning activities with which they formulate and test their ideas, draw conclusions and inferences, and pool and convey their knowledge in a cooperative learning environment (Woolfolk, 2016). In this wise, constructivism transforms the student from a passive recipient of information to an active participant in the learning process. Under the teacher's guidance, students actively construct their knowledge rather than just mechanically ingesting knowledge from the teacher or the textbook.

Constructivism is also often misconstrued as a learning theory that compels students to "reinvent the wheel." In fact, constructivism taps into and activates the student's innate curiosity about the world and how things work. Students do not reinvent the wheel but, rather, attempt to understand how it turns, how it functions. They become engaged by applying their existing knowledge and real-world experience, learning to hypothesize, test their theories, and eventually draw conclusions from their discoveries (Educational Broadcasting Corporation, 2004).

The focus in a constructivist classroom is shifted from the teacher to the students. The classroom thus, does not simply serve as the venue for 'pouring' knowledge into empty passive vessels (students), but a place where students are encouraged to actively participate in the process of learning. In that context the teacher functions for the most part as a facilitator who coaches, mediates, prompts, and aids students in developing and assessing their understanding and thus their own learning. In that vein, the teacher's greatest task is to ask the right questions that will ensure that the students are able to do what is required of them – critical thinking. Such teachers and their students do not perceive knowledge as inert facts to be committed to memory, but rather as dynamic, ever-changing view of the world in which we live.

The conceptual base/framework for the study is an amalgam of conceptual change approach and the Model of Educational Reconstruction (MER). The conceptual change approach was adapted from Duit and Treagust (2003). According to them, conceptual change has been used as a framework for studying students' cognition and learning since the 1980s. In their review of the literature on conceptual change, Duit and Treagust made it clear that the concept of conceptual change has varied meanings assigned to it. However, for their review, conceptual change had the meaning of learning in domains where pre-instructional conceptual structures of learners have to be fundamentally restructured in order to give room for understanding the intended knowledge – the acquisition of science concepts.

In this study, the conceptual change approach to teaching was adopted because usage of the term connotes learning science using the constructivist's perspective (Duit, 1999) and also it has been used in studies of learning and instruction in science and other domains (Guzetti & Hynd, 1998; Mason, 2001; Schnotz, Vosniadou, & Carretero, 1999). Thus, since this study, in addition to exploring students conceptual understanding of genetics concepts, was also concerned with the development of a teaching strategy for improving students' conceptual understanding of concepts in genetics, it was appropriate to employ the conceptual change approach as a conceptual framework for the implementation of the developed intervention. Also, because the teaching strategy was developed based on the alternative conceptions of students identified beforehand, using the Model of Educational Reconstruction (MER) in addition to the conceptual change approach to help design an appropriate teaching strategy to help improve students' conceptualizations in genetics, was well in order.

The MER is also based on the constructivist epistemology (Duit, Kattmann, Gropengiesser, Komorek & Parchmann, 2012). It has been suggested that one possible and practical way of dealing with conceptual change in a classroom may lie in the theoretical *Model of Educational Reconstruction* (e.g., Duit, Gropengiesser, & Kattmann, 2013). Within this framework, teaching "is not mainly or even solely oriented to scientific issues but includes students' conceptions as well" (Duit & Komorek, 1997, p. 341) in a bid to fill the void between a science subject matter and students' respective alternative conceptions (Duit, Gropengiesser, & Kattmann, 2005). The result is that the model takes three components into account: the analyses of the science subject, the investigation of the students' conceptions, and designing learning activities based on the results from the first two components.

Accordingly, employing the model encompasses determination of students' alternative conceptions, followed by a consideration of the revealed conceptions in teaching approaches. Some authors suggest the presentation of the alternative conceptions using the constructivist teaching sequence, as a suitable teaching strategy for ensuring conceptual development and change (Driver, 1989; Driver & Oldham, 1985).

For this study, employing the model involved first analysing the literature to ascertain the difficulties students have with genetics concepts, and ascertaining the concepts that serve as the basis for understanding other concepts within the subject. Thereafter, students' alternative conceptions and other conceptual difficulties with the basic concepts (chromosome, DNA and gene) gleaned from the literature were explored. Also, teachers' perceptions of genetics as a subject, areas they emphasize and methods they employ in teaching genetics were also explored. Finally, the results from the analysis of genetics as a subject, determination of students' conceptions and teachers' perceptions in addition to recommendations from the literature were used to design the O-D-R conceptual change approach. It was this approach that was used as the intervention to help improve students' conceptual understanding of genetics concept.

The *gene* concept

The *gene* concept has undergone many changes in definition over the years. The Mendelian concept of the gene was that a gene is a discrete unit of inheritance that affects a phenotypic character (Campbell & Reece, 2005). The concept *gene* has gone through swift changes over the last few decades. It was originally believed to be the unit of inheritance as well as a DNA-based unit that changes to RNA and forms polypeptides that are crucial for life. *Genes* were considered to form the blueprint of an organism (Campbell & Reece, 2005).

Previously it was thought that one gene makes one polypeptide. This was referred to as the "one gene-one polypeptide model". This notion has undergone a great transformation. The change occurred after it was discovered that genes were not single units but a long continuum, and that there was the concept of alternative splicing and trans-splicing. This means that genes can split into fragments, with each fragment coding for different polypeptides.

Additionally, there are control regions on every gene. These control regions must not necessarily remain close to the coding region or exons and introns or somewhere upstream over the DNA or even on the same chromosome. Once these control regions or switches were found to be coding regions that initiate and regulate the formation of protein, there was a leap frog in genetic research, particularly in the concept of a gene as the causation of diseases and a basis for inheritance.

Also, it has been found out that evidence exists that indicates that fused polypeptides may be coming from codes on two separate genes coding for separate genetic protein products. This has been found to be more common than it was formerly thought. It is the discovery of these fused polypeptides that has led to the refutation of the one gene-one polypeptide model, thereby giving rise to a new definition of the gene as "a region of DNA whose final product is either a polypeptide or an RNA molecule".

This means gene products, whether they be proteins or RNA, may have more than one specific or non-specific loci or locations and the regulatory DNA or promoter regions that regulate the RNA and protein coding are classified within the "gene associated regions". These may be located within, near or further upstream from the coding regions or may be located on different chromosomes altogether.

It is worthy of note that the GAST Biology textbook, Biology for Senior Secondary Schools, defines the gene as "a single unit of heredity, forming part of the chromosomes of eukaryotic cells", (Nyavor & Seddoh, 1991, p. 374).

The *DNA* concept

Deoxyribonucleic acid or DNA is a molecule that contains the instructions an organism needs to develop, live and reproduce. These instructions are found inside every cell, and are passed down from parents to their offspring.

DNA structure

DNA is made up of monomers called nucleotides. Each nucleotide contains a phosphate group, a sugar group and a nitrogenous base. The four types of nitrogen bases are adenine (A), thymine (T), guanine (G) and cytosine (C). The order of these bases is what determines DNA's instructions, or genetic code. Human DNA has around 3 billion bases, and more than 99 percent of those bases are the same in all people, according to the U.S. National Library of Medicine (NLM).

Similar to the way the order of letters in the alphabet can be used to form a word, the order of nitrogen bases in a DNA sequence forms genes, which in the language of the cell, tells cells how to make proteins. Another type of nucleic acid, ribonucleic acid, or RNA, translates genetic information from DNA into proteins.

Nucleotides are attached together to form two long strands that spiral to create a structure called a double helix. If you think of the double helix structure as a ladder, the phosphate and sugar molecules would be the sides, while the bases would be the rungs. The bases on one strand pair with the bases on another strand: adenine pairs with thymine, and guanine pairs with cytosine.

DNA molecules are lengthy - so lengthy that they cannot fit into cells without the right packaging. To fit inside cells, DNA is coiled tightly to form structures called chromosomes. Each chromosome contains a single DNA molecule. Humans have 23 pairs of chromosomes, which are found inside the cell's nucleus.

DNA discovery

DNA was first observed by a German biochemist named Frederich Miescher in 1869. But for many years, researchers did not realise the importance of this molecule. It was not until 1953 that James Watson, Francis Crick, Maurice Wilkins and Rosalind Franklin figured out the structure of DNA - a double helix - which they realized could carry biological information.

Watson, Crick and Wilkins were awarded the Nobel Prize in Medicine in 1962 "for their discoveries concerning the molecular structure of nucleic acids and its significance for information transfer in living material." Franklin was not included in the award, although her work was integral to the research.

The *chromosome* concept

In the nucleus of each cell, the DNA molecule is packaged into thread-like structures called chromosomes. Each chromosome is made up of DNA tightly coiled many times around structural proteins such as histones that support its structure.

Chromosomes are not visible in the cell's nucleus—not even under a microscope—when the cell is not dividing. However, the DNA that makes up chromosomes becomes more tightly packed during cell division and is then visible under a microscope. Most of what researchers know about chromosomes was learned by observing chromosomes during cell division.

Each chromosome has a constriction point called the centromere, which divides the chromosome into two sections, or arms. The short arm of the chromosome is labeled the p arm. The long arm of the chromosome is labeled the q arm. The location of the centromere on each chromosome gives the chromosome its characteristic shape, and can be used to help describe the location of specific genes (https://ghr.nlm.nih.gov/primer/basics/chromosome)

Students' alternative conceptions of, and learning difficulties with the concepts gene, DNA and chromosome

This section is intended to give insights into students' alternative conceptions as well as other difficulties the science education literature report on. It is my hope that these insights will aid in the expansion of the view of the issues relating to research question 1. As has already been noted above, constructivism being the framework on which many research pertaining to learners' thinking and learning is based, the section includes a description of several interpretations of what is considered to be the constructivists' approach to learning and knowing. It also includes an indication of the term adopted for describing students' conceptions. Students' difficulties with the understanding of the scientific concepts genes, DNA and chromosomes, as well as their alternative conceptions with regards to same are discussed.

Constructivism and learning – General perspectives

Crucial to constructivism is the notion of human knowing and the nature of scientific knowledge. It also includes the perception of what the learning process is and how knowledge that has been acquired is authenticated. In science education, these concepts are quite fundamental. Indeed, it is as Treagust et al (1996) assert, constructivism serves as a very powerful theoretical resource that maximizes student learning. In addition, it helps explain major empirical findings with regards to importance of students' pre-instructional conceptions in the learning process, and facilitates interpretations of outcomes of instruction. This, thus, is the main significance of the constructivist view for research, teaching and learning.

Two basic principles are used to describe constructivism, namely psychological and epistemological principles (Mutimucuio, 1998). Both principles stress that knowledge is inseparable from the individual having it. The psychological principle postulates that knowledge is not passively received, but rather actively built up by a cognizing individual (Wheatley, 1991). The main idea of psychological constructivism is that a person learns by mentally organising and re-organising new information or experiences. The organisation happens partly by relating new experiences to prior knowledge that is already meaningful and well understood. This implies that what the learner already knows is of utmost importance in the teaching learning process. New incoming material has to be filtered by the prior and pre-instructional ideas for the learner to be able to make sense out of it. The psychological principle is mostly accepted by science educators.

The epistemological principle of constructivism states that the function of cognition is adaptive and helps the learner to build feasible explanations of his/her experiences of the world. Thus, knowledge about the 'world outside' is seen as a human construction (Mutimucuio, 1998). As such, constructivism focuses on how learners construct practical and worthwhile knowledge, and not as the representation of truth.

A careful consideration of the two principles of constructivism reveals that they consist of many of the components of Piaget's (1972) genetic epistemology, which is the genesis of discussions of constructivism in education. At the center of Piaget's genetic epistemology is the learner, who is considered as an active agent creating his own reality. Jean Piaget considers actions as serving as the foundation upon which reality is built. Thus, constructivism as envisioned by Piaget, could be said to be based on an epistemology that stresses the mind's constructive activity in the creation and understanding of experience. In this sense, knowledge is considered to be a constant human construction endeavour (Mariani & Ogborn, 1991).

According to Mutimucuio (1998), Driver and Bell made a summary of several specific views on learning in line with the fundamental principles of constructivism stressed in the preceding paragraphs. The suggestions made with regard to the implications of the constructivist process of learning are:

1. "learning outcomes depend not only on the learning environment but also on the knowledge, purposes and motivations of the learner;

2. learning involves the active construction of meanings. Meanings constructed by students from what they see or hear may or may not be those intended. Construction of a meaning is influenced to a large extent by our existing knowledge;

3. the personal and social construction of knowledge is a continuous and active process on the part of the learner;

4. meanings once constructed are evaluated and can be accepted or rejected;

5. learners have the final responsibility for their learning; and

6. there are patterns in the types of meanings students construct due to shared experiences with the physical world through natural language" (p. 26)

In addition, Mutimucuio (1998) asserts that Driver made three additional noteworthy contributions to the features of constructivism. These expanding additions involve the social organization and modes of interaction between learners and between learners and teachers. They are:

> 7. "teachers also bring their prior conceptions to learning situations not only in terms of their subject knowledge but also their views of teaching and learning. These can influence their way of interacting in classrooms;
>
> 8. teaching is not the transmission of knowledge but involves the organization of the situations in the classroom and the design of tasks in a way which promotes scientific learning; and the curriculum is not that which is to be learned, but a program of learning tasks, materials and resources from which the students construct their knowledge" (p. 26).

Other authors have expressed similar opinions about constructivism. For instance, Ertmer and Newby (2013) in their study on comparing the critical features of behaviourism, cognitivism and constructivism from an instructional design perspective, assert that, though 'constructivists do not deny the existence of the real world, they contend that what we know of the world stems from our own interpretations of our experiences' (p.55). This implies that meanings that we have are our own creations. In other words, we do not acquire meanings but arrive at them through our own elucidations.

Also, Bada (2015) asserts that constructivism is a teaching and learning approach hinged on the premise that cognition (learning) is achieved through the process of "mental construction." The process of mental construction in this case involves the fitting of new information into what is referred to as the relevant prior knowledge. This implies that students learn by fitting new information together with what they already know. When we encounter something new, we have to reconcile it with our previous ideas and experience, maybe changing what we believe, or maybe discarding the new information as irrelevant. In any case, we are active creators of our own knowledge. To do this, we must ask questions, explore, and assess what we know. In the classroom, the constructivist view of learning can point towards a number of different teaching practices. Generally, then, it means encouraging students to use active techniques (experiments, real-world problem solving) to create more knowledge and then to reflect on and talk about what they are doing and how their understanding is changing. The teacher's role is thus to ensure he/she understands the students' pre-existing conceptions, and guides the activity to address them and then build on them (Oliver, 2000).

Two of the crucial concepts within the constructivist learning theory which help in understanding how an individual creates new knowledge are accommodation and assimilation. Assimilating helps an individual to incorporate new experiences into the old ones. This causes the individual to develop new positions, rethink what were once misunderstandings, and evaluate what is important, ultimately altering their perceptions. Accommodation, on the other hand, is reframing the world and new experiences into the mental capacity already present. Individuals first imagine a particular fashion in which the world operates. When things do not operate within that context, they then accommodate and reframe the expectations and conclusions. Constructivism is, as such, hinged on the belief that learning is affected by the context in which an idea is taught as well as by learners' beliefs and attitudes. This means that the same piece of knowledge learned by learners with different beliefs and attitudes in different contexts, may lead to different meanings being constructed by the different learners.

If it is accepted that constructivist theory is the best way to explain learning, then it follows that in order to promote student learning it is necessary to create learning environments that directly expose the learner to the material being studied. This is so because it is by experiencing the world directly that the learner can develop meaning from them. This leads to the view that constructivist learning must of necessity take place within a suitable learning environment – the constructivist learning environment. One of the central tenets of all constructivist learning is that it has to be an active process (Tam, 2000); therefore, any constructivist learning environment must provide the opportunity for active learning to take place (Bada, 2015). In outlining Honebein's summary of what he describes as the seven pedagogical goals of constructivist learning environments, Bada (2015) stated the sixth goal as "To encourage the use of multiple modes of representation, (video, audio, text, etc.)" (p. 68). This is to say that the use of varied modes of representation such as videos, audio, text, audiovisuals, and so on, encourages the learner to actively participate in lessons. Thus ensuring that the learner constructs his own knowledge in different representational contexts.

Also, in listing Caine and Caine's 12 principles of constructivism, Bada (2015) stated the eleventh as "Learning is enhanced by challenge and inhibited by threat. The classroom climate should be challenging but not threatening to students" (p. 69). In the light of this, going the constructivist way, students learn best by being presented with tasks that challenge them to engage in effective construction of knowledge. In addition, his list of implications of constructivism for teaching and learning has the sixth point as the constructivist teacher is someone who engages students in experiences that demonstrates contradictions to initial understandings and then encourages discussion. This is similar to helping students to discard misconceptions or alternative conceptions by presenting them with instances that they cannot use their conceptions to explain. When that happens, learners tend to be receptive to the acquisition and retention of the scientifically accepted conceptions.

Furthermore, the idea of the constructivist teacher having the role of engaging learners in experiences and encouraging discussions between himself and the learners, is in line with the common idea of mediation. This is what social constructivists advocate; that though knowledge is as a result of personal construction, the process of construction is socially mediated (Bada, 2015). This consideration is derived from Vygotsky's social constructivism which emphasizes the importance of language in meaning making. It also embodies the fact that, although learners construct their own meaning of new phenomena, the meaning making process is always entrenched in the learners own social setting. This implies that the learning of scientific concepts should be within a sequence that involves learners being able to think, comprehend, and make decisions with the involvement of the teacher. Thus, for meaningful learning to take place, activity alone is not sufficient. This indicates that in constructivist learning situation, the help offered learners by the teacher is a vital component. This, it is believed, will guide learners to make constructions that result in learners acquiring the concepts and theories agreed upon by the scientific community.

In conclusion, the lesson objectives set by constructivist teachers must clearly specify the knowledge to be achieved by learners (Mutimucuio, 1998). In line with this, it is required on the part of teachers to assess the ideas and expectations learners bring to class i.e. learners' prior knowledge and anticipations of topics to be studied. In particular, teachers should aim at making clear the difference between scientific knowledge and everyday commonsense knowledge. (The scientific knowledge refers to a system of mathematically expressed concepts, relations, definitions and principles; commonsense knowledge is knowledge constructed through everyday experience or through interaction between members of a non-scientific community). It is the commonsense knowledge that serves as the main source of learners pre-instructional conceptions, which tend to be quite difficult to change by instruction. This is because these determine learners' sense-making process of information provided by the teacher or read from textbooks.

Vocabulary for categorising students' conceptions

Research question 1 is about the conceptions students hold. As such the vocabulary the relevant literature uses in describing students' conceptions are discussed here.

Pertinent to constructivism is the notion that students are not *tabula rasa* (blank slates) as the English philosopher John Locke suggested. Instead, the student comes to the classroom with ideas about what will be taught. These student ideas may originate from everyday experiences, language usage and 'improper' teaching (Wenning, 2008) as well as informal learning. These ideas may interact with the new ideas taught in class, thereby influencing the student's receptivity to the new ideas.

Within the existing literature, there are several terminologies for labelling students' conceptions. These include preconceptions (Novak, 1977), alternative conceptions (Driver & Easley, 1978), misconceptions (Helm, 1980), alternative frameworks (Driver, 1991), common-sense concepts (Halloun & Hestenes, 1985), initial conceptions (Chi, Slotta & De Leeuw, 1994), or everyday conceptions (Lewis & Kattmann, 2004). Several authors have issues with one or more of these terminologies. Read (2004), for instance, reports Sneider and Ohadi as writing that a number of researchers are opposed to the term 'misconception' because, from the student's viewpoint, the ideas expressed are logical. 'Preconceptions', naïve theories', and 'alternative frameworks' have been proposed as better terms for students' personal views that are at odds with modern scientific theories. Read further asserts that researchers who hold the Vygotskian view of situated learning also tend to object to the term 'misconception' on the grounds that a person may possess multiple, alternate mental representations of the same phenomena (Spada, 1994). Whilst the term 'misconception' emphasizes the wrongness of a student's conception, and can thus be seen as critical of the holder of the concept, it should be recognized that the alternate term 'naïve theory' is also value-laden. However, I use alternative conceptions as a neutral term for labeling students' conceptions.

Students' alternative conceptions are said to be based on "personal experiences" (Mills Shaw, Van Horne, Zhang & Boughman, 2008) and, particularly in the area of genetics, are influenced by the students' social environment (Born, 2007). These alternative conceptions differ from the conceptions that are "generally accepted by the scientific community" (Treagust, 1988, p. 159). The difference between the two conceptions may prevent students from understanding a taught scientific concept. Thus, students must of necessity change their alternative conceptions and reconstruct their knowledge towards the new "to-be-learned" conception which is acceptable to the scientific community (Read, 2004) within genetics education especially, by using reasoning processes (Lawson & Thompson, 1988). Thus, giving consideration to students' alternative conceptions within teaching must be a requirement for conceptual change (Posner, Strike, Hewson, & Gertzog, 1982).

Franke, Scharfenber and Bogner (2013) assert that accepting a to-be-learned scientific conception appears to be only conceivable when existing individual alternative conceptions and scientific ones are concurrently accepted in order to prompt a cognitive conflict. To achieve this, Franke et al cite Posner et al as pointing out four conditions to be satisfied. They are "(a) a currently held conception does not satisfy the learner; (b) any newly provided conception must be intelligible; (c) the learner must regard the new conception as plausible; (d) the new conception should lead to a fruitful research agenda" (p.1). However, the adoption of a to-be-learned conception does not occur suddenly but rather follows a slow, continuous learning process (Posner et al as cited in Franke et al.), also described as "conceptual reconstruction".

In addition to using the term 'students' alternative conceptions', I have also used the expression 'other conceptual difficulties' students have with the three concepts studied – gene, DNA and chromosome. These other conceptual difficulties are used for students' difficulties exhibited in answering the achievement test items which are neither scientifically accurate nor alternative conceptions. The scientifically accurate responses (SAR) as used in Chapters 3 and 4 are students responses that are in line with what the scientific community accepts, whereas the 'no response' (NR), is used when students fail to write any response to an item, or simply write 'No idea' as the answer.

Categories of students' alternative conceptions

A number of attempts have been made to categorise students' alternative conceptions in the literature (National Research Council [NRC]; Talanquer; and Yip; as cited in Adu-Gyamfi & Ampiah, 2019). The NRC categorisation used by Adu-Gyamfi and Ampiah (2019) were employed in this study to categorize the alternative conceptions exhibited by students. They are the following five categories:

1. Preconceived Notions – These are said to be popular student conceptions which are said to be based on their everyday experiences.

2. Nonscientific Beliefs – These are students' conceptions which have been developed from sources other than science education. The sources of these conceptions could be religious and (or) mythological teachings.
3. Conceptual Misunderstandings – These refer to students' conceptions that are developed from science lessons which fail to help students confront their preconceived notions and nonscientific beliefs.
4. Vernacular Misconceptions – These are said to be students' conceptions of scientific words which have other meanings in everyday life.
5. Factual Misconceptions – These refer to students' conceptions developed from false ideas that were learned in early ages but have not been challenged till adulthood.

As indicated by the above categories of alternative conceptions, there are several sources of alternative conceptions held by students. Some are said to be from everyday experiences, formal instruction, myths, curriculum and textbooks, language (especially the vernacular, where students have to shuttle between two or more dialects), religious teachings, as well as students' use of inadequate mental structures in learning related concepts (Chiu; Gooding & Metz; Guest as cited in Adu-Gyamfi & Ampiah, 2019).

Students' alternative conceptions of gene

Researchers of different nationalities have disseminated their findings about the alternative conceptions of the concept gene. The following are some of the documented alternative conceptions held by students about the concept gene as reported by Science Learning Hub (2011).

Genes and DNA are separate things – whereas a gene is a section of DNA, a considerable number of students, reportedly, think of genes as being distinct from DNA. Such students express the idea that genes are what make you resemble your family and that DNA are for identifying an individual.

Genes are only found in certain cells – although other than mature red blood cells, all other human cells have DNA, and thus genes, students have the view that genes are found in some cells, such as blood, brain and the reproductive system.

Different cells contain different genes – frequently students express the idea that different cells in the body contain different DNA. For instance, they think that the DNA in the skin is different from that in the eye. But the fact is that every cell in the body, except the gametes, contains the same DNA, and by extension, the same genes. Yet not every gene is expressed in every cell. For example, the genes that code for muscle proteins such as actin and myosin are only expressed in muscle cells and not in the other cells in the body, even though present in those other cells.

We are all unique because we have different genes – students tend to think that the distinctive differences between individuals is as a result of having different genes. The fact however, is that all humans have almost exactly the same genes, in the same order, along the chromosomes. The unique characteristics of individuals is the result of different combinations of alleles inherited from parents. Thus, individuals with a common parentage tend to be unique from each other. This variance in alleles results in a unique combination of traits. (Alleles are alternative forms of the same gene occupying the same locus on a chromosome).

Genes code directly for our traits – It is a common thought among students that genes are direct instructions for particular traits. The truth rather is, genes code for proteins that make up cells, tissues and organs that in the end, result in individuals' distinctive phenotypes.

Single genes code for specific traits – There is also the view among students that particular traits are always coded for by a lone gene. Most traits are complex and are the result of the interactions between a number of genes, although a few traits are determined by single genes. It is argued that this alternative conception among students could be as a result of the examples that teachers use when teaching genetics.

We only have genes for the traits that are displayed – Students have expressed the idea that it is only the traits that an organism displays that it has the genes for. Yet at any given locus, two alleles are located. Indeed, the different alleles of a gene usually have the same function, but may result in the exhibition of different phenotypes, based on which of the two alleles an individual has, as well as whether one of the alleles is dominant, or both are recessive.

Inheritance involves an averaging of the genes from both parents – Students envisage genetic inheritance as an averaging of the genes received from the two parents. Thus, to them, a short parent and a tall parent will give birth to an average height child. But then, our traits are usually controlled by a number of genes (polygenic inheritance). An offspring's genotype is a unique combination of genes from its parents. It is not just a mixing of genes from the parents. Also, the existence of dominant and recessive genes presupposes that an offspring may exhibit a single parent's characteristics.

In addition to these alternative conceptions reported by Science Learning Hub (2011), Lewis and Wood-Robinson (2000) also reported some common confusions and alternative conceptions that students in Britain who were nearing the end of their compulsory science education exhibited with regards to the basic concepts underpinning an understanding of biological inheritance. They found out that 20% of their sample (N=482) thought that genes are only found in specific cells, such as cells of the reproductive system. Furthermore, about 36% of their sample believed that cells only contain the genetic information they needed in order to perform their function.

This means that to these students, a particular cell, for example, muscle cell has only the genetic information needed to perform as muscle cell, eye cells have only the genetic information they need to function as eye cells, etc. Thus, there is the belief that genetic information needed by other cells to function cannot be found in other different cells. In addition, 14% of the sample appeared to believe that every cell contained different genetic information (possibly arising from the belief that genetic information is shared out at each cell division), according to Lewis and Wood-Robinson (2000). Also, 12% of the sample held the 'alternative basic belief that all cells from one individual will contain the same genetic information'. They further reported that 25% of the sample considered 'gene' to be bigger than 'chromosome'. 10% of the sample also believe that chromosomes were found in genes. It can thus be concluded that about 35% of the sample had the conception that the gene is bigger in size than the chromosome. Also, a number of responses to questions used as probes by the researchers (i.e. Lewis and Robinson) indicated that some students believe that all characteristics are determined by the genes - including behaviour and personality.

Still on students' alternative conceptions of the gene concept, Kilic, Taber and Winterbottom (2016) in their study found the following alternative conceptions with regards to the gene concept: *Genes that determine an individual's inherited characteristics are only found in sex cells. The gene for eye colour is located in the iris because iris is the part of the eye responsible for eye colour. The X and Y chromosomes, which are found in a sperm cell, carry all the genes*.

These students seem to believe that because genes are passed from parents to offspring, and because there is fusion of the male and female sex cells to form an offspring, then genes that determine characteristics must be in the sex cells only. Again, as concluded by Kilic, Taber and Winterbottom (2016), the students seem to believe that each cell contains genes specific to itself. This is in agreement with what is reported in other literature, that students think that cells contain only the genetic information they need to serve their functions (Lewis and Wood-Robinson, 2000; Lewis, Leach and Wood-Robinson, 2000)

The third alternative conception is also similar to the first, as in both cases the students appear to believe that all genes are borne by only the X and Y chromosomes. However, the difference between the two alternative conceptions is that, with the third, the students seem to have the idea that it is only the male sex cell, the spermatozoon that carries the genes.

Students' alternative conceptions of DNA

The DNA concept is equally rampant with alternative conceptions, according to literature (Saka, Cerrah, Akdemiz, & Ayas, 2006; Koksal & Akkaya, 2017). For instance, Koksal and Akkaya (2017) reported from their study that was intended to identify acquaintance, knowledge levels and alternative conceptions of eighth grade students about inheritance, that students have the following alternative conceptions about DNA concept: *DNA* *is the building structure of nucleic acids; DNA is a nitrogenous purine base in nucleic acid structure;* and *DNA is all of the genes in an organism.*

Also, Saka et al.'s study of Turkish students and teachers' understanding of three genetics concepts found that students have the following alternative conceptions with the DNA concept: *DNA is made of chromosome, DNA is single stranded, DNA is a piece of gene,* and *DNA makes one's blood type.*

The first of Saka et al.'s students' alternative conceptions of the DNA indicates that students' conception of the DNA structure is faulty. They have not been able to conceptualise that a single DNA molecule is condensed into a chromosome with the aid of proteins, and not the other way round. The second alternative conception is also an indication that students are having conceptual issues with the structure of the DNA. This is because the DNA being described as a double helix means that it is double stranded and single stranded. Also, students conception that DNA makes one's blood type may be as a result of the everyday parlance 'it's in the blood', where people are said to be related by blood, with the connotation that what makes people who are related to each other resemble one another is found in their blood, or that such individuals have the same blood types. And thus, as DNA is understood to be a hereditary material, then it must be what makes individual's blood types (according to the Turkish students).

Students' alternative conceptions of chromosome

From literature, students from different grade/educational levels exhibit a number of alternative conceptions about the concept chromosome (Koksal & Akkaya, 2017; Ozcan, Yildirm, & Ozgur, 2012; Kilic, Taber, & Winterbottom, 2016). Koksal and Akkaya's (2017) study of eighth graders acquaintance, knowledge and alternative conceptions about inheritance unearthed the following three alternative conceptions of the concept chromosome: *A chromosome is an organelle carrying an organism's hereditary characteristics; A chromosome is an administrative molecule in an organism; Chromosomes are structural units of nucleic acids (DNA, RNA).*

The first alternative conception carries the idea that all the characteristics in an organism are directly borne by a chromosome. However, the chromosome rather carries genes which encode the information needed to produce proteins that orchestrate nearly every function of a cell.

The second alternative conception in the list, *a chromosome is an administrative molecule in an organism* is ascribing the role of a DNA molecule to a chromosome. This means that students with this conception have a difficulty differentiating between the roles of chromosome and DNA.

Koksal and Akkaya's (2017) third and final alternative conception of chromosome (chromosomes are structural units of nucleic acids) carries the idea that chromosomes form nucleic acids.

Conceptual Development and Change

Conceptual development is viewed by some authors as consisting of the replacement of students' conceptions by scientific concepts (Culbert & Watt, 1983; Posner et al., 1982). Other authors see it in a different light. That is, conceptual change does not mean erasing/cancelling/extinguishing students' conceptions totally. The reasons being that (i) students' conceptions tend to be valuable in everyday contexts and thus are seen to be of value in future specific events; (ii) most adults, including experts, hold similar major features of the same conceptions in subject areas that they are not specialists in; (iii) it has emerged from research that it is not possible to completely eliminate old conceptions, and thus such tend to co-exist with the scientific conceptions (Mutimuciou, 1998). This means that when teaching, teachers should target enlargement of learners' conceptual structures and not focus solely on eradicating perceived alternative conceptions of students. The enlargement of learners' conceptual structures is what Gilbert and Watts, as cited in Mutimucuio, referred to as 'evolutionary change'. In their definition, they talked about the extension in richness and precision of meaning for students' frameworks. This evolutionary change is also said to view the path from learners' pre-instructional conceptions as a continuous change that starts the teaching from aspects of learners' conceptions that are nearer to the scientific conceptions to be learned. This implies that learners' prior conceptions need to be reconciled with the scientific conceptions that are taught in classrooms. Such a reconciliation will ensure that learners become aware of the inadequacies of their conceptions, and thus prepare them to be more receptive to the new (or scientific) concepts. For instance, with regards to the scientific conception of the gene, Venville and Treagust (1998) established an evolutionary process in which the previous (alternative) conceptions are reconciled with the new (scientific) conceptions.

Conceptual understanding of a concept is said to be a reflection of a student's ability to reason in settings involving the careful application of concept definitions, relations, or representations of either. To help students acquire this ability, there is the need to get them to see connections between what they are learning and what they already know (Balka, Hull, & Miles, 2015).

The constructivist teaching sequence in question has two main parts. Both parts consist of three phases. The first part consists of the *orientation* phase. This is followed by a discovery phase of the students' conceptions (*elicitation of ideas*), and a restructuring phase of the selected conceptions (*restructuring of ideas*) then follows. During these phases, a process of clarification and exchange takes place, where single conceptions are put in conflict with each other to allow the construction of new conceptions.

Furthermore, to ascertain the extent to which conceptual development and change have taken place during the teaching, the three phases of the first part in the sequence, are followed by the application of the new conceptions (*application of ideas*) as well as by an assessment of the changes which may have resulted (*review of change in ideas*). A comparison of the new and old (alternative) conceptions is then made to complete the constructive teaching sequence.

Methods and Strategies for Teaching Genetics

Different authors have suggested varied teaching approaches for teaching genetics. The following are what the literature recommends for teaching science in general and for teaching genetics in particular.

Research has shown that teaching exclusively using lecturing, even at the university level, is not the most effective way to help students become highly skilled in Science, Technology, Engineering and Mathematics (STEM) concepts (American Association for the Advancement of Science, 2011; Smith & Wood, 2016). It is thus recommended that strategies and techniques that encourage active learning, that is, using student-centered instructional techniques, be used in teaching STEM subjects. This, it is reported, results in sustaining students' interest in such subjects (Smith & Wood, 2016; Vickrey, Rosploch, Rahmanian, Pilarz & Stains, 2015). In addition, Smith and Wood reported the results of a recent meta-analysis that students taught using active learning, student-centered instructional techniques, interspersed with peer discussion and other group activities requiring analytical thinking, exhibited substantial increase in their learning. These techniques were also found to have led to a decrease in the drop-out rate in STEM courses at the undergraduate level.

Active learning is said to occur whenever experiences stimulate mental activities that lead to meaningful learning. Thus, clearly active learning subscribes to constructivism. Some active teaching methods for ensuring active learning occurs that have been recommended by researchers for teaching science in general, and genetics in particular are as follows:

Concept mapping (Jibrin & Zayum, 2012), concept cartoons (Keogh & Naylor, 1996), using the video, group discussion, brainstorming, experimentation, case studies, role play, individual students – class presentations, group projects. It is worthy of note that almost all of the genetics lessons that are found on the internet (YouTube, for example), are a combination of these active teaching/learning strategies. One particular lesson even includes a dance by a section/the whole class in explaining crossing over. Most of the lessons include the use of videos, improvised models, demonstrations using local/ordinary materials (for example, beads, strings, etc.) for helping students visualize concepts taught, as well as pictures of structures under discussion.

Thus when designing my lesson for aiding students' conceptual development of the three concepts – chromosome, DNA and gene – I used similar strategies and techniques. Chief among the strategies I employed were the use of audiovisuals (videos) and demonstrations.

CHAPTER THREE

RESEARCH METHODS

This chapter gives the explanation of the research design, population, sample and sampling procedure, instruments, data collection procedure, and data analysis. It thus gives a description of how the study was carried out. Details of what went into the data collection during each of the two stages of the study have been provided in this chapter. It has been organised into the following subheadings – Research Design, Population, Sampling Procedure, Data Collection Instruments, Data Collection Procedures, Data Processing and Analysis and Chapter Summary.

Research Design

The study explored the conceptual understanding of elective biology students with three basic concepts in genetics – Chromosome, DNA and Gene, in addition to developing and field-testing an instructional strategy for teaching these basic concepts in senior high school using the conceptual change approach. The instructional strategy was aimed at improving students' understanding in genetics. To help achieve this aim the triangulation convergence mixed methods design was employed (Creswell & Plano Clarke, 2018). This led to the collection of both quantitative and qualitative data which were analysed to answer the research questions. The triangulation in this convergence mixed methods design helped to bring together quantitative and qualitative sources of information to describe the teaching of the genetics concepts - chromosome DNA and gene.

In addition, the triangulation convergence mixed methods design helped to collect and analyse the quantitative and qualitative data on teaching and learning of the three concepts – chromosome, DNA and gene, separately and independently. The quantitative data collection (survey of teachers and students) was followed up with the qualitative data collection (interviewing of teachers and students' explanations on achievement test). Figure 1 is a diagrammatic representation of the triangulation convergence mixed method design employed.

As seen in Figure 1, phase 1 of the design involved both the quantitative and qualitative strands. For the quantitative strand, teachers' questionnaire and students' achievement test were used to collect data. The purpose was to explore elective biology teachers' attitudes, beliefs, opinions and practices with regards to teaching and learning genetics. In addition, the conceptions held by students who have been taught genetics at the senior high school on the three concepts – Chromosome, DNA, Gene - as well as challenges they encountered with learning genetics concepts were explored. For the qualitative strand, students and teachers were once again identified for data collection. Teachers responded to interviews and students, achievement test. The purpose was to triangulate the quantitative data on the teaching and learning of genetics at the quantitative phase with the qualitative data. The qualitative strand also helped in explaining why students had the conceptions they portrayed during the quantitative data collection. Thus, the qualitative strand helped explain and refine the problems identified at the quantitative strand.

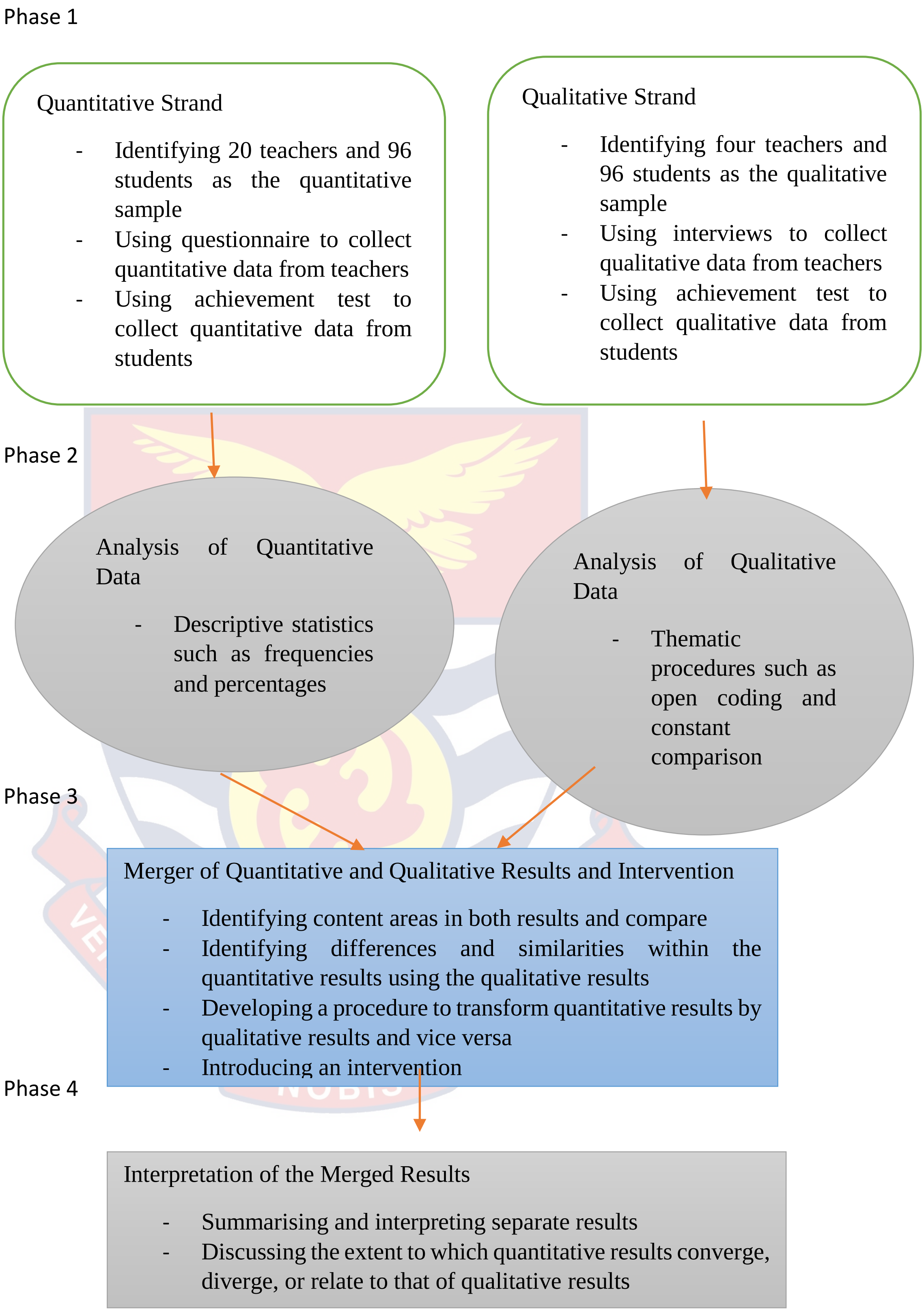

Figure 1: Diagrammatic representation of triangulation convergent mixed methods design adapted from Creswell and Plano Clark (2018).

At phase 2 of the design, the quantitative and qualitative data were analysed separately. The quantitative data analysis involved the use of descriptive statistics. The descriptive statistics used were frequencies, percentages, charts. The qualitative data analysis on the other hand, involved the use of thematic procedures such as open coding and constant comparisons. Additionally, sample statements were also used in the qualitative analysis in a bid to exemplify the types of conceptual understandings exhibited by the students. Also sample statements of teachers were used to support the themes relating to teachers' views, perceptions and attitudes on the teaching and learning of genetics.

A merging of the quantitative and qualitative results was undertaken at the third phase of the design. To accomplish this, four thematic areas were used to transform students' conceptions which were expressed as percentages and frequencies and presented as charts. The perceived nature of teaching and learning of genetics presented on the teachers' questionnaire were merged with teachers' views from the interviews. These were then transformed into graphs and charts. Based on the results from students' conceptual understanding and teachers' perceptions, views and perceptions on teaching and learning of genetics, an intervention, the O-D-R conceptual change approach was implemented by the researcher in a selected school. The implementation was done using a pre-test post-test single group experiment.

At the fourth and final phase of the triangulation convergence mixed methods design used for the study, interpretation of the merged results was done. This involved summarising and interpreting the separate results as well as discussing the extent to which quantitative results converge, diverge and relate to the qualitative results. This was done in order to make inferences and draw conclusions in line with the research questions that guided the study.

Population

The study was conducted in the Cape Coast Metropolis of the Central Region of Ghana. The Metropolis is noted for having some of the leading SHS in the country. The Cape Coast Metropolis therefore, attracts students from all over the country. There were 13 SHS made up of 10 public and 3 private schools. The study focused on only the public SHS where students offered the general science programme in each school.

The target population for the study comprised all biology teachers and biology students in the Cape Coast metropolis in the 2018/2019 academic year. The accessible population for the study were 56 biology teachers, 1600 SHS 3 and 40 SHS 2 biology students in 7 out of the 10 public SHS in the metropolis. The reason being that two of the schools were used in pretesting the instruments and students from one of the schools were unavailable for the study.

Sample and Sampling Procedure

In this study a multistage sampling technique was used to select 20 teachers, 96 SHS3 students and 14 SHS2 students for the study. The public SHS were selected for the study because they all offered the elective science programme. The 10 public schools (five single sex and five mixed) were stratified into single sex and mixed schools. The five single sex schools comprised two female and three male schools. The two female single sex schools were made to participate in the study but 2 out of the 3 male schools were selected by simple random sampling. Afterwards, four of the mixed sex schools were also selected using simple random sampling. During the main study, students from one of the eight schools were not available for the study. Thus students from seven schools finally participated in the study.

Of the 56 teachers, 24 were purposively selected. This is because they were the teachers teaching biology at the SHS 3 level at the selected schools and had taught genetics for three or more years. Of the 24 teachers, four were not available during the main study as they were engaged outside the school. Generally, the teaching experiences of the 20 teachers who finally participated in the study ranged between 3 and 17 years. The teachers were then stratified into four strata on the basis of their teaching experience as 3 – 6 years, 7 – 10 years, 11 – 14 years and above 14 years. As there was only one teacher with teaching experience above 14years (i.e. 17 years), one teacher each was selected from each stratum for interviewing, by simple random sampling. This gave a total of four teachers for interviewing. The genetics lessons of the teacher with 17 years teaching experience were observed. The reason being that he was very willing to be involved and during the interviews he was very forthcoming with detailed information about the issues raised about genetics teaching and learning.

From each of the seven schools, 17 students were selected using simple random sampling. This gave 119 students who should have participated in the study. However, 96 students responded to, and returned the Students' Achievement Test on Genetics. One out of the seven selected schools was selected by simple random sampling for the intervention stage of the study. At that school, 14 of 40 SHS 2 students were selected by stratified sampling. The 40 students were stratified into above average, average and below average based on their class assessment records. Five students from each stratum were selected by simple random. This gave 15 students for the intervention. However, one student was sick and could not participate in the study.

Data Collection Instruments

Three research instruments were developed for data collection. They were:

1. Teachers' Questionnaire on their Teaching Practices, Challenges and Nature of Genetics (TQTPCNG)
2. Students' Achievement Test on Genetics (SATG)
3. Interview Guide for Teachers on Effective Teaching Practices for Genetics (IGTETPG)

Teachers' Questionnaire on their Teaching Practices, Challenges and Nature of Genetics (TQTPCNG)

To obtain information on teachers' perception of teaching and learning, classroom practices, as well as challenges with the teaching of genetics, a multidimensional questionnaire (**TQTPCNG**) was developed. The **TQTPCNG** had seven sections – Sections A to G with a total of 36 items (see Appendix A). However, prior to the pilot test there were 42 item. Section A was the bio-data part. It consisted of items 1 to 8 which elicited information on their age range, sex, academic and professional qualifications as well as their teaching loads. Section B was on the difficult genetics topics for teachers and students. It spanned Items 9 and 10 (each of which had 12 sub items of the subtopics in genetics as outlined in the syllabus). Section C was about student characteristics that enhance the learning of genetics. It covered Items 11 to 15. In this section, teachers were required to indicate the degree of importance attached to students' characteristics, such as ability to think creatively, remember formulae and procedure, understand the use of genetics in the reals world, in order to do well in genetics. Section D was on teachers' perception of the nature of genetics. It covered Items 16 to 18. The items required the teachers to indicate their degree of agreement or disagreement with statements about the abstract nature of genetics, whether genetics is a formal way of representing the real world, and whether or not genetics is a practical guide for addressing real issues. Section E was on the perception of how students learning of genetics can improve. It was from Items 19 to 25. Here too teachers had to indicate their degree of agreement or disagreement with statements about how students perceived genetics. For example, statements about whether or not students see genetics tasks to be same even when represented differently, such as using symbols and pictures to represent the same information were included. Section F spanned Items 26 to 29. It was on the areas teachers tended to emphasise in their genetics lessons. The items elicited information on classroom strategies they emphasised during their genetics lessons, such as letting students work individually on tasks, using whole class interaction, and others. Section G was on the frequency at which they performed certain activities during their genetics lessons. For instance, they were to indicate how frequently they reviewed students' homework with them, how often they had to re-teach genetics concepts already covered. It covered Items 30 to 36.

Validity of the questionnaire: In constructing the questionnaire, the literature was first used to construct some of the items based on recommendations from the literature. Other items were constructed based on the experience of the researcher as an educator. Copies of the instrument were given to practicing teachers at the senior high schools for their inputs as to the appropriateness and relevance of the items. The teachers' views were used to improve the questionnaire before giving it to experts. Finally, I gave copies to experts in the Department of Science Education, University of Cape Coast for their perusal and inputs. I then used their inputs to drop three of the items leaving 39 items. The 39 item questionnaire was prepared and used for the pilot testing.

Reliability of the questionnaire: To fine tune the **TQTPCNG,** it was pilot tested on 10 teachers from the two public schools that were not included in the study. The 39 items were subjected to item analysis. Four of the items that were measuring different constructs were deleted leaving 36 items. The 36 item questionnaire was structured into seven sections – Sections A to G. Section A comprised eight items; B, two items; C, five item; D, three items; E, seven items; F, four items; and finally, G, seven items. Thereafter the reliability coefficients were calculated. This was to determine how reliable the instrument was. The reliability coefficients were found to be 0.75, 0.65, 0.74, 0.85, and 0.60 for Sections C, D, E, F and G respectively. The overall reliability coefficient of the questionnaire, however, was found to be 0.75.

Students' Achievement Test on Genetics (SATG)

To ascertain alternative conceptions held by students who had been taught genetics at the SHS, an achievement test (**SATG)** consisting of 14 items was designed (see Appendix B). It was divided into three sections – Sections A, B and C. Section A was on bio-data. It asked for the sex and age of respondents. Section B required students to indicate topics in genetics that they found challenging when taught. A list of 12 genetics topics were listed for them to choose from. Section C was on the meanings of the three concepts, relationships between them and applications of the concepts in real situations. Initially, there were 17 items on the SATG. The items required students to state their understanding of the concepts 'gene, chromosome and DNA'. The items were framed based on the specifications in the SHS elective biology syllabus with regards to the three concepts concerned – genes, DNA and chromosome. For instance, the syllabus requires that students will be able to 'explain and define terms used in genetics with examples' (Ministry of Education, 2010. p. 63). The terms listed include genes, chromosome, and DNA. Thus, Items 1, 5 and 6 on the achievement test asked students to indicate their understanding of the terms gene, DNA and chromosome. Items 2 to 4 required students to show their conception of the differences between the three concepts. Finally, Items 7 to 17 probed whether students could apply their understanding of the three terms in explaining real world problems. For instance, Item 13 required students to explain why siblings of same parentage looked different from each other.

The validity of the SATG was ensured by first checking the SHS Elective Biology Syllabus content with regards to the three concepts concerned (i.e. gene, DNA and chromosome). Furthermore, I gave copies to SHS elective biology teachers to comment on their appropriateness and difficulty level. Finally, I gave copies to science education experts in the Department of Science Education, University of Cape Coast for scrutiny and inputs.

The reliability of SATG was calculated after pilot testing it on 30 students. Each item scored 3 marks, where SAR (scientifically accurate response) = 3, OCDR (other conceptual difficulties) = 2, ACR (alternative conception response) = 1, and NR (no response) = 0. The reliability was calculated using Cronbach alpha. This was because the achievement test was not dichotomously scored as right or wrong. It was found to be 0.71. However, after item analysis, three of the Items – 15, 16 and 17 - were deleted as they were difficult. The final reliability coefficient was calculated to be 0.75.

Based on the information obtained with the SATG, the Pre- and Posttest achievement tests for checking the efficacy of the developed lesson for teaching the three concepts – chromosome, DNA and gene – were developed. These were labelled Pre SATG (Appendix E) and Post SATG (Appendix F) respectively. There were 14 items on both the pretest and posttest. However, the arrangement of the items on the posttest differed from that of the pretest. This was done in order to minimize the déjà vu effect of the pre-test on the posttest.

Interview Guide for Teachers on Effective Teaching Practices for Genetics (IGTETPG)

To further probe teachers' self-report about their teaching practices during their genetics lessons as elicited by the **TQTPCNG,** an interview guide (**IGTETPG**) was developed. It consisted of 13 items (see App C). Items 1 and 2 were a recap of the biodata and were about the number of years they have been teaching biology and their weekly teaching load. Item 3 elicited the importance teachers attached to their students understanding how genetics is used in the real world. Items 4 to 7 addressed the genetics concepts that both teachers and students found to be challenging and the steps teachers took to address them. Item 8 enquired about the instructional materials teachers generally used for their genetics lessons. Item 9 asked about how teachers got their students active during genetics lessons. Item 10 was about the frequency at which teachers gave homework to students. Item 11 asked whether or not teachers tended to resort to re-teaching when they deemed it necessary. Item 12 was about the teaching methods and strategies they usually employed in their genetics lessons. Finally, item 13 asked for other strategies they would recommend for colleague teachers to use.

Validity of the IGTETPG: To ensure the validity of the IGTETPG, the items were constructed in relation to literature reviewed. Furthermore, teachers' responses to items on the **TQTPCNG** were considered such that items on the IGTETPG would be able to probe for more details. Finally, to ensure content validity, copies were giving to experts in the Department of Science Education, University of Cape Coast for their inputs.

Transferability was used to ensure the external validity of the interview. This was because sufficient data on teacher interviews in relation to teaching and learning of genetics would be provided for readers and users of this current study.

Reliability of the IGTETPG: To ensure reliability of the IGTETPG, all the four teachers interviewed were asked the same basic questions and in the same order. In the case of teachers who brought up thought provoking issues, their views were used as further probing questions for the other teachers who were interviewed after them. Also, the interviews were conducted as dialogues between the interviewer and interviewees, such that the interviewer gave no hints or clues as to the expected responses. This helped in eliciting the teachers' own views of issues under discussion, and not preconceived ideas that they thought would please the interviewer. Thus, each interviewee was given time liberally to first think through questions posed and respond accordingly. This ensured that each teacher was not rushed but relaxed in order to organize his/her thoughts on issues well before responding to questions posed.

Data Collection Procedures

The data collection was done in three phases – the quantitative, the qualitative, and the Intervention phases. Quantitative and qualitative data were first collected concurrently but separately. This was followed by the intervention data collection. The data collection was done in the 2018/2019 academic year.

The quantitative data collection was done in February, 2018. On 1st February, 2018, the quantitative phase of the study began with the administration of a questionnaire on teaching genetics to 24 elective biology teachers. At the same time, an achievement test was administered to 119 SHS 3 students. The instruments were administered from school to school. It took two weeks to recoup almost all the administered questionnaires and achievement test scripts. The students' achievement test scripts were collected within one week (i.e. from 1st to 8th February, 2018), and the majority of the teachers' questionnaires were received two weeks after their being administered (i.e. from 1st to 15th February, 2019). However, four of the teachers' questionnaires were not returned and 27 of the students' achievement test scripts were not received.

The qualitative data collection was done alongside the quantitative one. First, four of the 20 teachers who responded to the questionnaire were interviewed one-on-one over a period of three weeks. Their teaching experiences at the SHS level were 5, 10, 13 and 17 years.

The third and final phase of this study was the intervention phase. This was also conducted in the 2018/2019 academic year. The 14 students who were randomly selected from a form two class were involved at this phase. These students were pretested with the Pre SATG. A week after the pre-test, the students were instructed with the three O-D-R Genetics Lessons (Appendices G). The instruction was done over three consecutive days. The post-test, Post SATG, was administered a week after the instruction. The O-D-R Genetics Lessons followed the following sequence: Orientation – Discovery – Restructuring.

The O-D-R Genetics Lessons used were based on the constructivist teaching approach adopted by Mutimucuio (1998). The constructivist teaching sequence in question consists of three phases. These are the *orientation* phase, followed by a discovery phase of the students' conceptions (*elicitation of ideas*), and a restructuring phase of the selected conceptions (*restructuring of ideas*) then follows. During these phases, a process of clarification and exchange takes place, where single conceptions are put in conflict with each other to allow the construction of new conceptions.

Furthermore, to ascertain the extent to which conceptual development and change had taken place during the teaching, the three phases in the sequence, were followed by the application of the new conceptions (*application of ideas*) as well as by an assessment of the changes which may have resulted (*review of change in ideas*). A comparison of the new and old (alternative) conceptions was then made to complete the constructive teaching sequence.

In line with the above approach three lessons were designed for teaching the three concepts – Chromosome, DNA and Gene – one lesson for each concept. Each lesson involved the three phases enumerated above i.e. Orientation, Discovery and Restructuring (O-D-R).

For each of the three lessons, the Orientation phase involved using concept cartoons to explore alternative conceptions learners have with the concept concerned. (Students are not informed that the ideas displayed on the concept cartoons are alternative conceptions.)

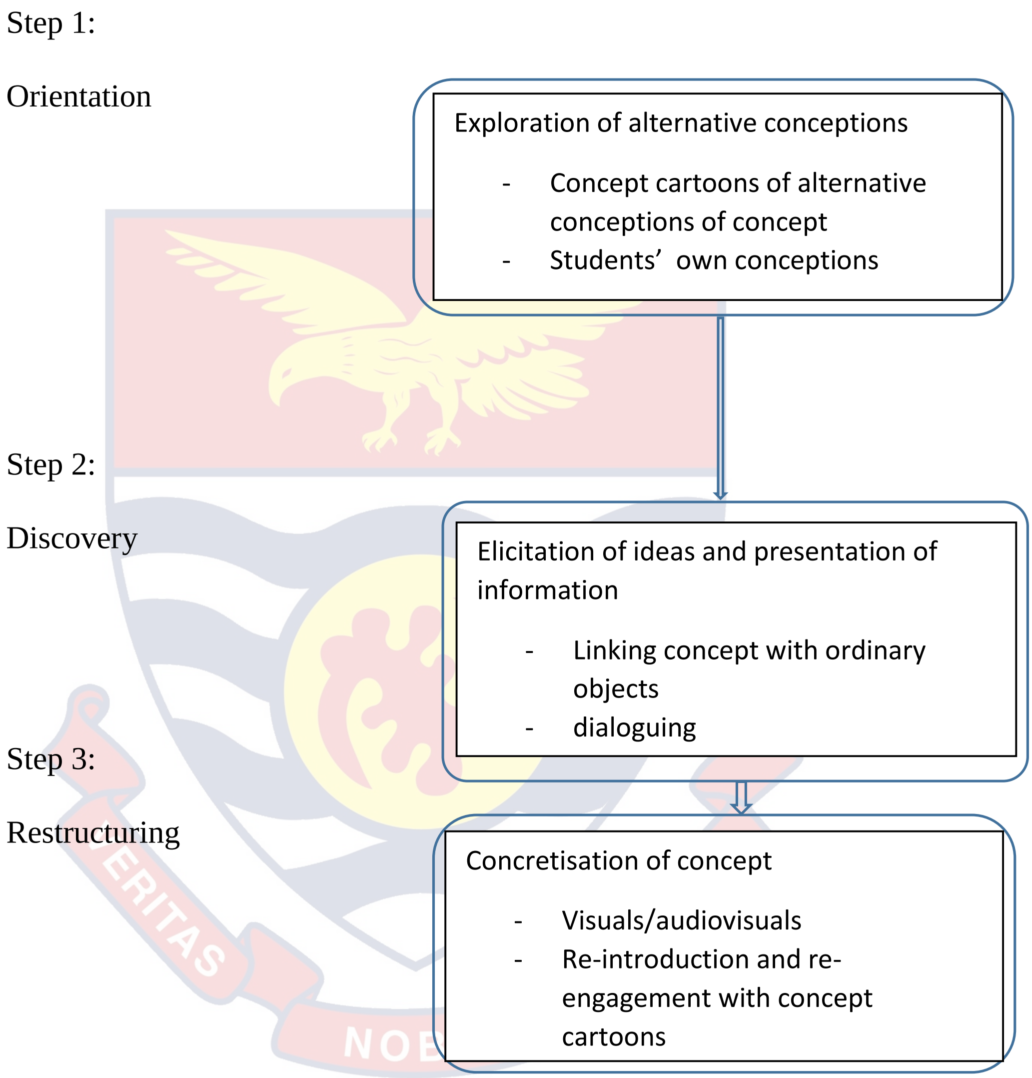

Figure 2: General sequence of the O-D-R lessons

The students were then asked to indicate the ideas in the concept cartoon that they agreed with and give reasons for their choices. This was done to help ascertain the alternative conceptions the current students may be holding in the concepts as a result of their everyday experiences. Also, the concept cartoons were used to help the students reflect on ideas that other learners have about concepts under study and compare it with their own (Joyce, 2006). This gave the teacher a glimpse of the potential alternative conceptions she may have to address to ensure students acquire the acceptable scientific concepts that are taught. Also, the concept cartoons will help the teacher gain an indication of the range of students' ideas within the class. They also aid in stimulating starting points for investigations (Joyce, 2006). It can thus be used to place students in a context suitable for making them curious for the acceptable scientific ideas that are about to be taught. Each student is invited to share his reason for the choice(s). Other students are allowed to challenge their colleagues' views/reasons to help them reshape their conceptions. The teacher then moves on to the second phase – Discovery.

The purpose of the Discovery phase was to elicit students' ideas about the concept under study. The teacher first shared information on the concept at stake. This served as an introduction to the activities to follow. Thus students were taking through activities that were designed to help them understand the concepts. For instance, when teaching the concept chromosome, the 'condensation' activity was used to help students visualise how the chromosome is formed. During the performance of the activities the teacher actively prompts students with relevant questions that help draw out what they are learning from them. The students were thus encouraged to express what they learn from the activities as their own ideas (Joyce, 2006). They were also given the opportunity to argue with each other. Thus, two types of dialogues are used here: Teacher-Student, and Student-Student dialogues. The Teacher-Student dialogues were used because they aid conceptual learning. Also, the Student-Student dialogues were used because they help students restructure their ideas appropriately

(Saloum & BouJaoude, 2017). This led to the third and final phase, the Restructuring phase.

The intention of the Restructuring phase is to help students grasp the scientific views of the concepts being taught. At the Restructuring phase the teacher projects videos depicting the concepts being studied. This was to enable students visualize most of the concepts which are at the micro level, especially the structures of the chromosome, DNA and gene. The videos are able to demonstrate aspects of the concepts that are impossible to recreate in a classroom. Before showing extracts of the video, students are asked to focus on some specific ideas that will be depicted. Each video session was preceded and followed with teacher questions that were intended to help students reorganize their thoughts about the concepts.

Finally, the concept cartoons that were used at the beginning of the Orientation phase were projected and students allowed to re-engage with the alternative conceptions.

Data Processing and Analysis

Research question 1 was answered using themes used in developing the instrument, percentages and frequencies from data on the achievement test (SATG). Students' responses to the 14 items on the SATG were first categorised into four response types – scientifically accurate responses (SAR); alternative conception responses (ACR); other conceptual difficulties responses, (OCDR); and no response (NR). Students' explanations and quotes were used to illustrate alternative conceptions and other conceptual difficulties.

To ascertain the categories of alternative conceptions exhibited by students on *chromosome*, DNA and gene, the five categories of alternative conceptions outlined by the National Research Council [NRC] and used by Adu-Gyamfi and Ampiah (2019) were employed in grouping the alternative conceptions. These were: Preconceived notions, Non-scientific beliefs, Conceptual misunderstanding, Vernacular misconception and Factual misconception. Fifty alternative conceptions identified under chromosome, DNA and gene were selected by simple random sampling and categorised. Alternative conceptions categorised as preconceived notions were ones that were found to be based on students' everyday experiences. Those categorised as non-scientific beliefs are alternative conceptions that were found to have been developed from sources other than science education, such as religious beliefs and myths. Alternative conceptions classified as conceptual misunderstanding were ones that were either preconceived notions or non-scientific beliefs that were not challenged by classroom instruction. Vernacular misconception alternative conceptions were those that were found to be students' understanding of scientific words that have other meanings in everyday life. Alternative conceptions categorised as factual misconceptions were false ideas students may have learned in early stages that had not been challenged to date.

For research question 2, percentages of the SAR and ACR were calculated and compared. Quotes from students' explanations were used to illustrate their alternative conceptions and scientific conceptions identified.

Data from the TQTPCNG and IGTETPG were analysed to answer research question 3. To ascertain their perceptions of genetics, their responses to 5 items on the TQTPCNC (i.e. Items 16 to 20) on a five-point Likert Scale scored as Strongly Disagree (SD) - 1, Disagree (D) - 2, Undecided (U) - 3, Agree (A) - 4, and Strongly Agree (SA), 5, were analysed using percentages, means and standard deviations. From the five-point Likert scale, the calculated means were categorised as any mean score below 2.5 was considered as disagree (negative perception) and any mean score above 3.4 was considered as 'Agree' (positive perception) and any mean score between 2.5 and 3.4 was considered as Undecided (neutral perception). To determine what teachers emphasized in their genetics lessons, their responses to four items (i.e. Items 26 to 29) on the TQTPCNG were used. Here, on a four-point Likert Scale scored as Almost No Lesson (ANL) – 1, Few Lessons (FL) – 2, Most Lessons (ML) -3, and Almost Every Lesson (AEL) – 4, the means and standard deviations of teachers' scores were calculated and analysed. The calculated means were categorised as 0.5 – 1.45 for "Almost No Lesson", 1.5 – 2.45 for "Few Lessons", 2.5 -3.45 for "Most Lessons", and 3.5 – 4.0 for "Almost Every Lesson". Also, to establish how teachers teach genetics, their scores on seven items on the TQTPCNG (i.e. Items 30 to 36) were analysed using means and standard deviations. Here, a five-point Likert Scale scored as 'Rarely/Never' (R/N) -1, 'Often' (O) – 2, 'Very Often' (VO) – 3, 'Almost Always' (AA) – 4, and 'Always' (A) – 5 was used. From the five-point Likert scale, the calculated means were categorised as 0.5 – 1.45 for "Never", 1.5 – 2.45 for "Often", 2.5 – 3.45 for "Very Often", 3.5 – 4.45 for "Almost Always" and 4.5 – 5.0 for "Always". The results for the analysis were compared with teachers' interview responses, from the IGTETPG. In that regard, excerpts from teachers' responses were used.

Research question 4 was answered using percentages and themes. Percentages were used to display students' performance on both the pretest and posttest. To examine the effectiveness of the conceptual change approach students' explanations on the pretest were compared to those on the posttest. To further explore the effectiveness of the O-D-R conceptual change approach, comparisons of the explanations of students taught with the O-D-R approach and students who were not taught with the O-D-R approach in the first phase of the study were made.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the results and discussion of the findings from the study. The results are presented by research question followed by the discussions of the findings from each research question.

Students' alternative conceptions and other conceptual difficulties with chromosome, DNA and gene.

Research question 1 sought to find out alternative conceptions and other conceptual difficulties on chromosome, DNA and gene. To achieve this, the categories of students' responses on chromosome on the SATG were first determined. Table 1 presents the proportions of categories of students' responses on each of the four items under chromosome.

Table 1: Percentage of Categories of Students' Responses on Chromosome (N = 96)

ITEM	SAR		ACR		OCDR		NR	
	n	%	n	%	n	%	n	%
2	5	5.2	40	41.7	43	44.8	8	8.3
4	44	45.8	12	12.5	25	26.1	15	15.6
5	20	20.8	29	30.2	26	27.1	21	21.9
7	23	24.0	11	11.5	38	39.6	24	25.0

Source: Field data (Dzidzinyo, 2019)
SAR – scientifically accurate response; OCDR - other conceptual difficulties response; ACR – alternative conception response; NR – No response

Table 1 shows that generally, students gave responses covering all the four response categories in answering questions on chromosome. Though some of the students' explanations were in the domain of scientific responses for each of the four items, majority of the responses were in the domain of alternative conceptions and conceptual difficulties in students' explanations. It is only on Item 4 that almost one-half of the students provided scientific responses.

Item 4 sought to find out whether students had the conceptual scientific understanding that a chromosome has the loci where genes or genetic markers are located, such that it can be said that a chromosome bears genes and not vice versa. On this item, only 15.6% of the students indicated "Yes" to the statement "Can one gene contain many chromosomes?" This means that 51.1% students indicated "No" to the statement and 33.3% did not respond yes or no to the statement. As stated earlier, the presence of 12.5% alternative conceptions in students' responses can be seen as follows:

Alternative Conceptions: With regards to responses in the alternative conception domain, 5.2% students explained that chromosomes are found in each gene. This is not correct, as a chromosome serves as the locus of a gene and therefore cannot be contained in a gene. The following are excerpts of students' explanations reflecting this alternative conception:

> "Yes. This is because the sex cells produce twenty three chromosomes each which together become forty-six chromosomes in one gene" (ACR21).

> "One gene can contain twenty pairs of chromosomes. In all forty-six chromosomes, twenty-three from the mother and twenty-three from the father" (ACR39),

Some students (3.1%) explained that there are 23 pairs of chromosomes in every organism. However, the fact is that the 23 pairs of chromosomes talked about are the number of chromosomes in each somatic cell of *Homo sapiens*, and not of every organism. In other words, these students did not have the scientific conception that different organisms have different chromosomal numbers. An excerpt is:

> "Yes. Because every individual organism contains 46 chromosomes" (ACR85).

Still, other students (2.1%) also had the alternative conception that many chromosomes are borne by a single gene. However, it is rather chromosomes that bear genes. Excerpts of this are:

> "One gene contain many chromosome" (ACR86).
>
> "Yes, because gene carries chromosomes from parents which are more than one" (ACR93).

In trying to explain their answer, some students (2.1%) had difficulty understanding that in terms of size chromosomes are larger than genes. Such students expressed the alternative conception that a chromosome is contained in a gene because it is very small, implying that the gene is bigger than the chromosome. For example,

> "Yes, because chromosomes are very small" (ACR 82).
>
> "Yes, because the chromosomes make up the gene and they are very small" (ACR 93).

Other Conceptual difficulties: In the domain of other conceptual difficulties, students had difficulty explaining the composition of chromosome. Scientifically, a chromosome is said to be the result of the condensation of chromatin. However, students after indicating that chromosome cannot be contained in a gene explained that chromosomes are condensed forms of 'structures'. An excerpt is as follows:

"No. Because the chromosomes are the condensed form of structures" (OCDR88).

Item 5 sought to find out whether students had the scientific conceptual understanding that a chromosome consists of a molecule of DNA packaged with proteins. Only 20.8% of students' explanations were scientifically accurate, with 21.9% of the students providing no explanations to Item 5. The majority of students' responses (57.3%) provided were in the domains of alternative conceptions (27.1%) and other conceptual difficulties (30.2%).

Alternative conceptions: For Item 5, students' responses that were in the alternative conceptions domain were varied. Some students' (9.4%) explanations conveyed the alternative conception that a chromosome consists of a number of DNA molecules. However, scientifically, every single chromosome consists of a single DNA molecule tightly packed with packaging proteins. Excerpts are:

"A chromosome consists of several DNA molecules" (ACR06).

"A chromosome is made up of many DNA molecules …" (ACR 12).

Another alternative conception some students (6.3%) portrayed in their explanations to Item 5 is that a number of chromosomes make up a DNA molecule. This is an alternative conception because a chromosome consists of a single DNA molecule tightly coiled around proteins. The following excerpts from students' responses exemplify this alternative conception:

"A DNA is made up of chromosomes which contain genetic information" (ACR 22).

"…chromosomes are contained in the DNA" (ACR 25).

"The DNA contains chromosomes which are threadlike …" (ACR 35).

Some students' (6.3%) explained that chromosome can be equated to DNA or is another form of DNA. However, scientifically, a chromosome is an organized structure of DNA and proteins. It is a single piece of coiled DNA consisting of many genes, regulatory elements and other nucleotide sequences. Indeed it is only at Prophase 2 of mitosis that chromosomes appear and remain condensed through the various stages of mitosis. Typifying this alternative conception are the following excerpts:

"DNA are stranded chromosomes" (ACR 87).

"… The chromosome is a stable form of the DNA" (ACR 26).

In other instances other students' (2.1%) explanations portrayed the alternative conception that a chromosome is formed from a part of DNA. However, this is not the case as a chromosome's formation involves a whole DNA molecule being tightly packed with proteins. The following is an excerpt of this alternative conception:

"DNA is a very long strand of genetic material. A part of it is used for the formation of a chromosome" (ACR 09).

Some students (6.3%) also drew to explain the structure of a chromosome. However, the drawings demonstrated that they had alternative conceptions with regards to the structure of a chromosome. For instance ACR76 drew an H-like structure and labelled it as 'chromosome'. Yet chromosomes are drawn rather as X-shaped structures. ACR 80, on the other hand, drew the X-shaped structure of chromosome but labelled the tip of one chromatid as 'chromosome', and two chromatid tips as 'DNA'. Another student, ACR36, drew an animal cell-like structure and labelled the outer boundary as chromosome, an inner 'organelle's outer boundary as DNA and dots within the 'organelle' as genes. Also, another (ACR 59) drew a circular structure with a convoluted mass inside. The circular boundary was labelled as chromosome and the convoluted mass, as DNA. (See Appendix G).

Other conceptual difficulties: Though students understood that chromosomes are thread-like in structure, they had difficulty understanding what they are made of. They were not sure that a chromosome contained DNA. An excerpt of this conceptual difficulty is:

> "… Chromosomes are threadlike and may contain DNA molecules" (OCDR 04).

For Item 2, majority (86.5%) of students' explanations were in the domains of alternative conceptions and other conceptual difficulties. This is because 44.8% of students' explanations were alternative conceptions and 41.7% were other conceptual difficulties. This indicates that only 5.2% of the responses were scientifically accurate and 8.3% were in the no-response domain.

Item 2 sought to find out whether students had the conceptual understanding that in terms of size a chromosome is bigger than a DNA molecule as the chromosome consists of a DNA molecule tightly wrapped around packaging proteins. However, students explanations laid bare a number of alternative conceptions including the following:

Alternative conceptions: Some students (9.4%) had the alternative conception that an aggregate of chromosomes forms a DNA molecule. However, scientifically, it is the condensation of a DNA molecule by way of it being tightly coiled around packaging proteins that rather results in the formation of a chromosome. An excerpt of this is:

> "DNA molecule is a set of grouped chromosomes hence DNA molecule may be larger than chromosomes" (ACR29).

Other students (3.1%) had the alternative conception that chromosome and DNA are of the same size. However, the chromosome is thicker than the DNA and as such is visible under a light microscope, unlike the DNA. An excerpt is as follows:

> "A chromosome is a structure in the cell nucleus that contain DNA, protein and other structural protein … It is similar in size to DNA" (ACR 43).

Another alternative conception gleaned from students' explanations to Item 2 is that chromosome is the content of DNA. This alternative conception was expressed by 2.1% students. However, scientifically, since a DNA molecule tightly coiled around packaging proteins forms a chromosome, it can be said that a chromosome rather contains DNA. An excerpt is as follows:

> "… Chromosomes are also contain in the DNA" (ACR41).

Some students' (3.1%) explanations also indicated that they had the alternative conception that the chromosome being bigger than the DNA is because a number of DNA molecules come together to form a single chromosome. However, the chromosome is thicker or bigger in size than the DNA because each chromosome consists of a DNA molecule that has been tightly coiled around packaging proteins. An excerpt reads as follows:

"The chromosome is much bigger than a single DNA molecule as the DNA is the building block for the chromosome. That is the chromosome is just a pack of various strands of DNA" (ACR02).

Other students' (24%) explanations, furthermore, indicated that they had the alternative conception that chromosome is a single stranded structure whereas DNA is double stranded making the chromosome smaller than DNA. However, as has been repeatedly stated a chromosome consists of a DNA molecule (which is double stranded), and packaging proteins, thereby making the chromosome bigger than the DNA. Excerpts are:

"A chromosome is relatively smaller than a DNA molecule. This is because a chromosome is made of a single strand but a DNA is made of a double strand" (ACR22).

"A chromosome is a single strand of repeated gene units whilst a DNA molecule is made of two strands of chromosomes twisted about each other as a double helix. …" (ACR23).

Other conceptual difficulties: Some students (17.7%) had difficulties explaining why the chromosome is bigger than the DNA. For instance, after correctly indicating that chromosome is bigger in size than DNA, they failed to explain why. The following are excerpts:

"Chromosome is larger than the DNA molecule" (ACR 12).

"A chromosome is larger than DNA" (ACR 24).

For Item 7, the majority (51.1%) of students' explanations were in the alternative conceptions and other conceptual difficulties domain. This is because 24.0% of students' explanations were scientifically accurate and 25.0%

failed to express any conception about whether or not there are more chromosomes in a cell than there are genes.

Item 7 sought to find out whether students had the conceptual understanding that there are fewer chromosomes in a cell than there are genes. This is because a single chromosome has the loci for several genes. On this item, only 11.5% of the students answered "Yes" to the statement "In a single cell, would there be more of chromosomes or genes?" This means that 5.2% of the students responded "No" to the statement, and 83.3% did not respond "Yes" or "No". Once again, students' explanations brought to light a number of alternative conceptions. The following were noteworthy:

Alternative Conceptions: Students' explanations indicated that they had the alternative conception that there are twice as many chromosomes in a cell as there are genes. This alternative conception was expressed by 2.1% students. However, scientifically, a single chromosome bears several genes. Excerpts of students' explanations depicting this alternative conception include:

> "… because a gene is made up of two chromosomes. As a result about twice as many chromosomes as genes will be found in a single cell" (ACR 06).

> "… One gene contains more chromosomes and therefore the existence of a gene means the number of chromosomes will double …" (ACR 27).

Other students' (1.0%) explanations portrayed the alternative conception that chromosome exists in circulatory system to transfer traits.

However, chromosomes are found in nuclei of all cells of an organism except in mature red blood cells. An excerpt is:

> "In a single cell there will be more of chromosomes because in the circulatory system only the combined structure which is the chromosome exists and performs its function of transferring traits" (ACR 09).

Still another alternative conception from students' explanations is that chromosomes are contained in genes and are thus more in a cell as compared to genes. 8.4% students expressed this alternative conception. However, as stated repeatedly, chromosomes rather bear genes, and are thus less in a cell than genes. Excerpts include:

> "… Genes contain chromosome and since gene can contain more than one chromosome at a time …" (ACR 24).
>
> "There will be more of chromosomes since chromosomes are contained in genes" (ACR27).
>
> "…a gene can contain more chromosomes and is so obvious when the cell is dividing" (ACr33).

Other conceptual difficulties: Students found it difficult explaining whether it is chromosome which is more in a cell or genes which are more. Their explanations are thus not clear cut. Some (5.2%) of them are of the impression that in some cells there are more chromosomes than genes because only gene characteristics are present. This connotes the idea that in other cells there will be more genes. However, that is not the case. Excerpts are as follows:

> "In a particular cell there could be more chromosomes. Example is the

sperm cell which has 23 chromosomes. …may also have gene traits at specific intervals" (OCDR 60).

"More [chromosome] because every cell contains chromosomes but some gene characteristics" (OCDR86).

Students had difficulty understanding that if genes are subunits of the chromosome, then a single chromosome can have a number of genes located on it, thereby resulting in a cell having more genes than chromosomes. 5.2% students had this conceptual difficulty evident in their explanations. Excerpts read as follows:

"There will be more of chromosomes. Genes are subunits of chromosomes" (OCDR53).

"In a single cell there will be more of chromosomes because …the genes are only found on the chromosomes" (OCDR41).

Categories of Students' Alternative conceptions in Chromosome

To ascertain the categories of alternative conceptions exhibited by students on *chromosome*, the five categories of alternative conceptions outlined by the National Research Council [NRC] and used by Adu-Gyamfi and Ampiah (2019) were employed in grouping the alternative conceptions. These are: Preconceived notions, Non-scientific beliefs, Conceptual misunderstanding, Vernacular misconception and Factual misconception. Fifty alternative conceptions identified under chromosome were selected by simple random sampling and categorised. Figure 3 presents the frequencies of each of the five categories.

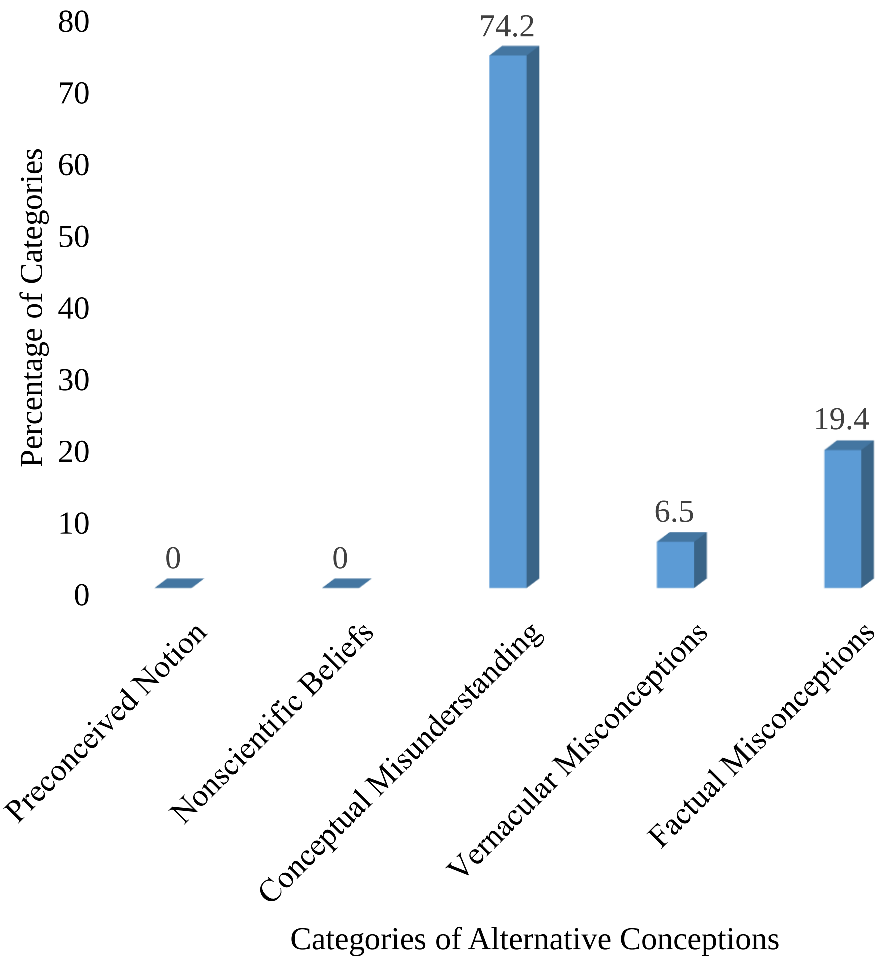

Figure 3. Bar graph of the percentage categories of alternative conceptions in chromosome.

Source: Field data (Dzidzinyo, 2019)

The results from Figure 2 indicate that two of the five categories of alternative conceptions were not present. Among the alternative conceptions students had with chromosome, there were no nonscientific beliefs and preconceived notions. This is because none of the students' explanations fell into these categories. With respect to conceptual misunderstanding category, majority (74.2%) of the alternative conceptions students had with chromosome were in this category as students' conceptions may not have been addressed by science classroom instruction. Some students (16.0%) used their non-science understanding that chromosomes can be found in genes and DNA in answering the questions. Excerpts are as follows:

> "The DNA molecules contain numerous genes whereas in each gene can be found chromosomes. Therefore, it can be said that chromosomes can be found in DNA" (ACR 40).
>
> "…because a gene is made up of two chromosomes. As a result, about twice as many chromosomes as genes will be found in a single cell" (ACR 06).

Other students (22.1%) used their non-science understanding that a gene contains 23 pairs of chromosomes. Excerpts of this conception are:

> "Yes. This is because the sex cells produce twenty-three chromosomes each which together become forty-six chromosomes in one gene" (ACR 21).
>
> "Yes. Because there are 23 pairs of chromosomes so one gene can contain many chromosomes" (ACR 39).

Other students (12.0%) further used their non-science understanding that there are twice as many chromosomes as there are genes. Excerpts are:

> "…because a gene is made up of two chromosomes. As a result about twice as many chromosomes as genes will be found in a single cell" (ACR 06).
>
> "...One gene contains more chromosomes and therefore the existence of a gene means the number of chromosomes will double …" (ACR 27).

Other students (24.1%) also demonstrated their non-science understanding in chromosome. This is because they explained that chromosomes aggregate to form DNA. Excerpts are:

"DNA molecule is a set of grouped chromosomes…" (ACR 29).

"…Chromosomes are also contained in the DNA" (41).

With regards to factual misconceptions, 19.4% of the students' alternative conceptions in chromosome fell in this category as students' conceptions developed from false ideas which may not have been challenged. Some students (13.6%) used the false idea that chromosomes are contained in DNA. Excerpts are as follows:

"Chromosomes are also contained in the DNA" (ACR 41).

"The DNA molecules contain numerous genes whereas in each gene can be found chromosomes. Therefore, it can be said that chromosomes can be found in DNA" (ACR40).

Other students (3.9%) used the false idea that chromosomes can be equated to DNA. Excerpts are:

"DNA are stranded chromosomes" (ACR 87).

"… The chromosome is a stable form of the DNA" (ACR 26).

Other students (1.9%) used the false idea that the DNA molecule is simply folded into a chromosome. An excerpt is as follows:

"The DNA molecule is folded into the chromosome" (ACR 60).

Also, 6.5% of the students' alternative conceptions in chromosome were identified as vernacular misconceptions as students' conceptions of scientific words may have other meanings in everyday life. Some students (4.3%) used the everyday meaning that there is the carrying of certain 'structures' from parents to offspring. An excerpt is as follows:

> "…gene carries chromosomes from parents which are more than one" (ACR 93).

Other students (2.2%) used the everyday meaning that traits are transferred from parents to offspring through the blood (or circulatory system). An excerpt is as follows:

> "In a single cell there will be more of chromosomes because in the circulatory system only the combined structure which is the chromosome exists and performs its function of transferring traits" (ACR 09).

Students' alternative conceptions and other conceptual difficulties with *DNA* concept

Research question 1 further looked at the alternative conceptions and other conceptual difficulties pertaining to the concept DNA. To achieve this, the categories of students' responses under DNA on the SATG were first determined. Table 2 presents the proportions of categories of students 'responses on each of the two items on DNA.

From Table 2, it can be seen that generally, students gave responses covering all the four response categories in answering questions on DNA. Though some of the students' explanations were in the domain of scientific responses for each of the two items, the alternative conceptions and conceptual difficulties in students' explanations far outnumber the scientific conceptions (about 70.0%). Also, on the whole, students' explanations that fell within scientific response domain were lower than the explanations that fell within both

Table 2: Percentage of Categories of Students' Responses on DNA (N = 96)

Item	SAR		ACR		OCDR		NR	
No.	n	%	n	%	n	%	n	%
6	8	8.3	45	46.9	19	19.8	24	25.0
8	9	9.4	45	46.9	9	9.4	33	34.4

Source: Field data (Dzidzinyo, 2019)
Where N – Total number of students who participated in the study; n – number of students who gave each response type; SAR – scientifically accurate response; OCDR - other conceptual difficulties response; ACR – alternative conception response; NR – No response

the alternative conception and other conceptual difficulties domains. On both items, the scientific responses were below 10.0%.

Item 6 sought to find out whether students had the conceptual understanding that a distinct segment of a DNA molecule makes up a gene. For Item 6, majority (66.7%) of students' explanations fall within the alternative conception and other conceptual difficulties domains. This is because 46.9% of students' explanations were alternative conceptions and 19.8% were other conceptual difficulties. Only 8.3% of students' explanations were scientifically accurate making it clear that a segment of the DNA molecule forms a gene.

Alternative conceptions: Some students (2.1%) had the alternative conception that DNA is made up of proteins. However, scientifically, a DNA is a polynucleotide consisting of individual nucleotides each of which is made up of a phosphate group, a sugar and a nitrogenous base. Excerpts of students' responses that typify this alternative conception are:

> "Both the DNA and the gene are made of proteins (amino acid sequence)" (ACR06).

"DNA are long strands of protein molecules that take part in cell division …" (ACR28).

Yet another alternative conception gleaned from some students' (2.1%) explanations is that DNA is a trait. This is the same alternative conception evident from students' explanations to Item 5 as indicated earlier. However, scientifically, the DNA only bears the gene which code for an individual's trait. This alternative conception is borne out by the following excerpts of students' responses:

"…DNA is also the unique trait that constitute the structure of the cell of the human system" (ACR 10).

"DNA is a very specific trait that one has which is very unique from others, but gene are the characteristics the one picks from birth" (ACR 86).

Other students' (35.4%) explanations also indicated that they had the alternative conception that a DNA molecule forms a gene. However, scientifically, a distinct section of a DNA molecule forms a gene, making it true that the DNA chemical is contained in a gene, a whole DNA molecule does not form a gene. Excerpts of students' responses that exemplify this alternative conception follow:

"A gene is an entire DNA sequence of a living thing" (ACR53).

"DNA is a molecule that contains genetic information of an organism but a gene refers to all DNA sequence" (ACR 45).

Yet another alternative conception evident from students' explanation is that specific DNAs are coded for by genes. This alternative conception was expressed by 2.1% students. However, scientifically, genes code for proteins that determine a trait, they do not code for DNAs. An excerpt of this alternative conceptions is:

> "Genes code for specific DNA. That is a specific portion of the DNA strand that carries a particular function" (ACR 79).

Students' explanations also indicated that they had the alternative conception that DNA contains traits passed on to offspring. 5.2% students expressed this idea. However, scientifically, DNA consists of genes which determine traits. The following are excerpts of the responses from students that illustrate this alternative conception:

> "The DNA contains the traits that is passed to the offspring which is the gene" (ACR 84).

> "Gene contains specific traits which are transferred from parents to offspring while DNA consists of all the genes" (ACR 88).

Other conceptual difficulties: In addition to the alternative conceptions students exhibited, they had difficulty conceptualising the link between DNA and gene. Thus their explanations were not clear as to the actual connection between the two. 14.6% students demonstrated this conceptual difficulty. Excerpts include:

> ",,, a gene copies segments on a whole DNA strand" (OCDR 05).

> "The DNA and the gene are both responsible for the transfer of characters from the parent to the offspring" (OCDR 36).

Also, a number of students (5.2%) drew to illustrate their conception of the relationship between DNA and gene. Scientifically, a drawing showing this relationship should be the DNA helical structure with a section of it demarcated and labelled as a gene. However, students' drawings depict conceptual difficulties. A student (OCDR71) drew somewhat of a helical structure, labelled the top as genes and the bottom as DNA. Another (OCDR13) drew dots bounded by a circle, and labelled the dots as genes and the circle as DNA. Still another (OCDR49) drew a circle with two large inverted commas at the centre and labelled it as gene, and drew a three-cord structure at the side and labelled it as DNA. (See Appendix G)

Item 8 sought to find out whether students have the conceptual understanding that an organism's DNA is the same in all its cells. For Item 8, 56.3% of students' explanations were in the alternative conception and other conceptual difficulties' domains. This is because 46.9% of students' explanations were alternative conceptions and 9.4% were other conceptual difficulties. However, 34.4% of the students failed to express any idea about the concept.

For Item 8, 24.0% of the students answered "Yes" to the statement "Is the DNA in a single skin cell different from the DNA in a single muscle cell?" This means that 31.3% answered "No" to the statement and 44.8% neither responded "Yes" or "No". As stated earlier students explanations had alternative conceptions that can be seen as follows:

Alternative conceptions: Some students' (32.3%) explanations indicated that they had the alternative conception that different cells have different DNAs. However, scientifically, DNA is the same in every cell of an organism. Excerpts of students' responses exemplifying this alternative conception are as follows:

> "...DNA coding in the skin is programmed to call for proteins which will produce more skin cells. This same idea applies to the single muscle cell" (ACR01).

"Because skin cell will show a different characteristic from a muscle cell. So the information in either DNA's should be different" (ACR18).

"…different genetic information is needed to produce different proteins that are needed for the function of the location required" (ACR59).

Other students (14.6%) also had the alternative conception that different DNAs in different cells have different gene combinations as they perform different functions. However, scientifically, the DNA being the same in every cell of an organism presupposes that the genes borne on the DNAs are also same throughout the cells in an organism. Excerpts of responses depicting this alternative conception include:

"…they have different gene combinations of the genes to produce a desired effect" (ACR03).

"…because different genes are codes for different characteristics" (ACR 43).

"…because each DNA found in a cell contains a specific sequence that codes for a particular gene…" (ACR 61).

Other conceptual difficulties: Additionally, some students who stated that DNA in different cells in an organism are the same found it difficult explaining why it is so. For instance, some students (3.1%) said the skin cell and muscle cell DNAs are the same because:

"…they are all found in the cells" (OCDR 83),

"…all cells are made up of chromosomes" (OCDR 76),

"…they perform the same function" (OCDR 95).

In much the same vein, others (6.3%) who said cells in an organism had the same DNA, failed to give any explanation for their answer. An explanation given by a single student was that the DNAs are the same because:

> "the DNA in both the skin cell and muscle cell identifies the person uniquely" (OCDR 44).

Categories of Students' Alternative Conceptions in DNA

In order to establish the types of alternative conceptions exhibited by students in DNA, the NRC five categories of alternative conceptions (Adu-Gyamfi & Ampiah, 2019) were once again used. They are: Preconceived notions, Nonscientific beliefs, Conceptual misunderstanding, Vernacular misconception and Factual misconception. In line with what was done for alternative conceptions in chromosomes, 50 alternative conceptions in DNA were selected by simple random sampling and categorized. Figure 4 presents the frequencies of each of the five categories.

The results from Figure 4 show that two of the five categories of alternative conceptions were absent. Of the alternative conceptions students had in DNA, the categories of nonscientific beliefs and vernacular misunderstandings were not identified. 35.5% of the students' alternative conceptions in DNA were identified as preconceived notions as students' popular conceptions appear to be based on their everyday experiences. Some students (17.8%) used their everyday conception that different living organisms have different characteristics to explain that the skin cell will have different DNA from the muscle cell. The following are excerpts of students' explanations in that vein:

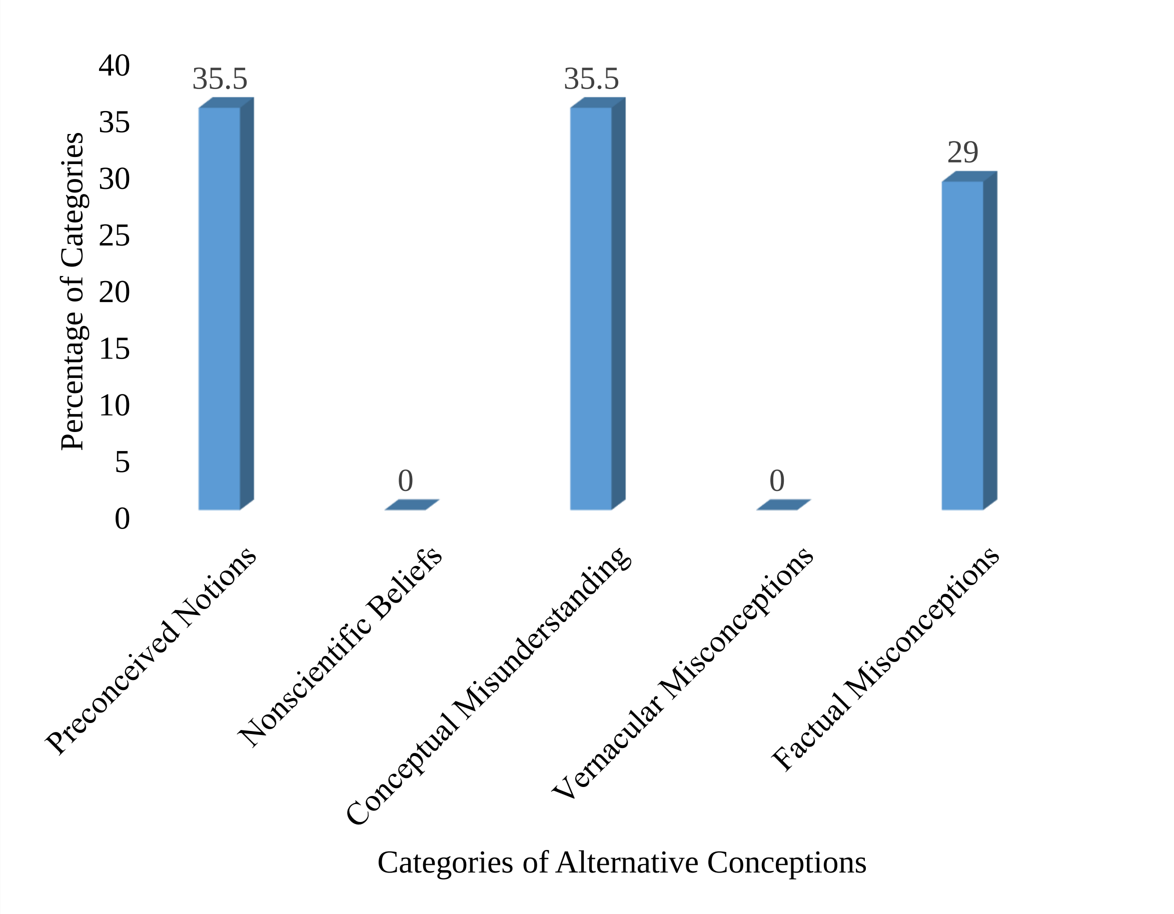

Figure 4: Bar graph of the percentage categories of alternative conceptions in DNA

Source: Field data (Dzidzinyo, 2019)

"The DNA in a single skin cell is different from the DNA in a single muscle cell because they do have functions to perform which are different…" (ACR 08).

"Yes. Because skin cell will show different characteristic from a muscle cell. So the information in either DNA's should be different" (ACR 18).

"The DNA in a single skin cell will differ from that of a muscle cell. Because the functions or the information the DNA carries might not be the same" (ACR 20).

Other students (9.9%) used their everyday conception that parents' traits are transferred to offspring. Excerpts are as follows:

> "DNA is a very specific trait that one has which is very unique from others, but gene are the characteristics the one picks from birth" (ACR 86).

> "The DNA contains the traits that is passed to the offspring which is the gene" (ACR 84).

> "Genes contain specific traits which are transferred from parents to offspring while DNA consists of all the genes" (ACR 88).

Other students (7.9%) also used the everyday conception (gleaned from the mass media) that DNA is for identification. Excerpts are as follows:

> "…the DNA in both the skin cell and muscle cell identifies the person uniquely" (ACR 44)

> "DNA is found in living beings which determines their form and used to identify a person" (ACR 59).

For conceptual misunderstanding, 35.5% of the students' alternative conceptions were found to be in that category as students' conceptions may have developed from science lessons that failed to help students confront their preconceived notions and nonscientific beliefs. Some students (13.8%) used the everyday notion that DNA in different cells of an organisms' body consists of different genes. Excerpts of students' explanations are as follows:

> "DNA in a single skin cell will be different from DNA in a single muscle cell. This is because they are made of different genes or nucleotide sequences" (ACR 17).

> "…because each DNA found in a cell contains a specific sequence that code for a particular gene…" (ACR 61).

Other students (21.7%) used the everyday notion that since different cells perform different functions, DNA contains instructions for performing different tasks. Excerpts are:

> "DNA is found in the nucleus and contains instructions for the performance of different tasks and so the instructions the DNA will give in a single skin cell and the instructions in a single muscle cell will differ" (ACR 34).
>
> "The DNA in a single skin cell is different from the DNA in a single muscle cell because they do have functions to perform which are different…" (ACR 08).

Furthermore, 29.0% of the students' alternative conceptions were present as factual misconceptions as students' conceptions may have developed from false ideas that were learned in early years but had not been challenged. Some students (26.9%) used the false idea that DNA is made of protein. Excerpts of students' explanations include:

> "…DNA is a protein material…" (ACR 42).
>
> "Both the DNA and the gene are made of proteins (amino acid sequence)" (ACR 04).

Other students (2.1%) used the false idea that DNA is the information passed from parents to offspring. An excerpt is as follows:

> "Gene contains the information that will be passed to the offspring. DNA is the information that will be passed on to the offspring" (ACR 66).

Students' alternative conceptions and other conceptual difficulties with *gene* concept

Research question 1 additionally, looked at the alternative conceptions and other conceptual difficulties pertaining to the concept gene. To achieve this, the categories of students' responses under gene on the SATG were first determined. Table 3 presents the proportions of categories of students' responses on each of the seven items on gene.

From Table 3, generally, students gave responses covering all the four response categories in answering questions on gene. Though some of the students' explanations were in the domain of scientific responses for each of the seven items, there were the presence of alternative and conceptual difficulties in students' explanations.

Table 3: Percentage of Categories of Students' Responses on Gene (N = 96)

Item	SAR		ACR		OCDR		NR	
	n	%	n	%	n	%	n	%
1	9	9.4	62	64.6	22	22.9	3	3.1
9	30	31.3	29	30.2	22	22.9	15	15.6
10	3	3.1	54	56.3	6	6.3	33	34.4
11	0	0.0	66	68.7	2	2.1	28	29.2
12	16	16.7	31	32.3	17	17.7	32	33.3
13	3	3.1	58	60.4	18	18.8	17	17.7
14	20	20.8	38	39.6	3	3.1	35	36.5

Where N – Total number of students who participated in the study; n – number of students who gave each response type; SAR – scientifically accurate response; OCDR - other conceptual difficulties response; ACR – alternative conception response; NR – No response
Source: Field data (Dzidzinyo, 2019)

On all but two of the seven items, the students' explanations that were in the alternative conceptions and other conceptual difficulties domains were above 50%; the majority (87.5%) was on Item 1.

Item 1 sought to find out whether students have the conceptual understanding that a gene is a segment of a DNA molecule or a discrete unit of hereditary information consisting of specific nucleotide sequence in DNA (or RNA in some viruses). For Item 1, 87.5% of students' explanations were in the alternative conceptions and other conceptual difficulties' domains. This is because 64.6% of the explanations were alternative conceptions and 22.9% were other conceptual difficulties.

Alternative conceptions: Students explanations on Item 1 indicated that they have the alternative conception that the gene is a particle that is of protein in nature. 5.2% students expressed this alternative conception. However, scientifically, the gene being a discrete section of a DNA consists of nucleotides and not amino acids. Excerpts are as follows:

> "A gene is a particle located on a particular point on a larger structure known as a chromosome…" (ACR 02).
>
> "The particles that are protein in nature. They carry information that can be transferred from parent to offspring" (ACR 85, ACR 86).

Other students (9.4%) also explained that gene expresses trait. However, scientifically, a gene encodes the instruction that allow a cell to produce a specific product, usually a protein. This alternative conception is exemplified by the following excerpt:

"A gene is a molecule which expresses a particular characteristic or trait due to the nature of the allele it possesses" (ACR 07).

Most students' (21.9%) explanations also indicated that a gene transfers characteristics from parents to offspring. However, scientifically, a gene only contains the coded instruction for building proteins that result in the expression of a characteristic. Excerpts that typify this alternative conception are:

"Gene is a unit on the chromosome that is responsible for the transfer of characteristics or features from parents to offspring" (ACR 25).

"Gene is a basic unit located in chromosomes and are responsible for the transmission of characters from a parent to the offspring" (ACR 37).

"Gene is the unit responsible for transferring heritable characters from parents to their offspring" (ACR 54).

Other students (10.4%) explained that a gene contains traits or characteristics of an organism. However, as stated earlier, a gene only bears the instruction for making a protein that results in the expression of a trait. The following are excerpts of students' explanations exemplifying this alternative conception:

"Gene refers to a hereditary material, or is a hereditary unit found in the chromosomes that contains traits or characteristics of an organism" (ACR 39).

"Gene contains the characteristic traits transferred from parents to offspring" (ACR 84).

In other instances some students (9.4%) explained that gene is simply a trait. However, as has been repeatedly stated, scientifically, the gene gives the instruction to produce a protein responsible for the expression of a trait. Excerpts of students' explanations are as follows:

"Gene is a trait that is contained in parent chromosome which determine the traits of an offspring" (ACR 78).

"Gene is a hereditary trait" (ACR 96).

Other students had difficulty conceptualising that a gene is a segment of a DNA molecule, or that it is a discrete unit of hereditary information consisting of nucleotide sequence in DNA (or in RNA in some viruses). Some of them (2.1%) expressed the alternative conception that genes are materials that help in determining the sex and characteristics of an individual. An excerpt is:

"Genes are materials that contain chromosomes of human beings that help in the determination of sex and characteristics of the individual or makes an individual different from another" (ACR 27).

Still some students (2.1%) also demonstrated an alternative conception about what a gene is made up of. They expressed that a gene is a string of a number of chromosomes. However, scientifically, a gene has its locus on a single chromosome. An excerpt is:

"A gene is a chain of chromosomes which contains genetic information" (ACR 22).

Other students (4.2%) had the alternative conception that a gene is the structure that makes up the DNA. However, scientifically, the gene being a discrete unit of the DNA implies that it contains the DNA chemical, but nucleotides rather form the structure of the DNA. An excerpt is as follows:

"A gene is the structure that makes up the DNA strand" (ACR 24).

Other conceptual difficulties: Other students (11.5%) had difficulty explaining that a gene is a portion of the DNA/RNA molecule, or a sequence of DNA or RNA nucleotides. They described the gene as a position of the DNA strand. An excerpt is as follows:

> "A gene refers to a particular position of the DNA strand which is made up of a particular nucleotide sequence that is transcribed and coded for protein formation" OCDR60.

Other students (5.2%) also had difficulty explaining that a gene codes for. Scientifically, a gene codes for gene products such as proteins and RNA. These students equated proteins to character (or traits). An excerpt is as follows:

> "Gene … codes for a particular protein or character" (OCDR74).

Still some students (5.2) were confused about the nature of genetic information carried by genes. Instead of explaining that genes bear nitrogenous basis (adenine, cytosine, guanine and thymine/uracil) that determine the type of proteins to be synthesized, these students explained that a gene carries genetic information in the form of amino acids. An excerpt is as follows:

> "A gene … carries genetic information such as sequence of amino acids for a protein" (OCDR44).

Item 9 sought to find out whether students had the conceptual understanding that an allele is a variant form of a specific gene, or one of two or more versions of a mutation at the same locus on a chromosome. For Item 9, 53.1% of students' explanations were in the alternative conception and other conceptual difficulties domains. This is because 30.2% of the explanations were alternative conceptions and 22.9% were other conceptual difficulties. Still, 15.6% did not express any idea about an allele, as they either left the space blank or indicated they had no idea of the concept.

Alternative conceptions: Some students (7.3%) explained that alleles are characters found on genes. However, scientifically, alleles being variations of a gene code for the instruction used by a cell to produce molecules, usually proteins that result in the expression of characters. An excerpt of students' explanations exemplifying this is:

"Alleles are characters that can be found on genes. Example: a gene for height may contain alleles of shortness or tallness" (ACR 05).

Other students (22.9%) explained that an allele is in a gene. However, scientifically an allele is a variation of a gene and thus is not a receptacle for a gene. An excerpt is as follows:

"An allele is located on a particular or specific loci of a chromosome which is responsible for the characteristics of an individual since it is in the gene" (ACR 08).

Other conceptual difficulties: Students found it hard explaining the link between an allele and a gene. 7.3% students exhibited this difficulty. Their explanations are not clear. Scientifically, an allele is a different form of a gene occupying the same locus. Excerpts are:

"An allele is a gene which is made of two different genes" (OCDR32).

"An allele is part of the gene. A gene is made of the dominant and recessive allele" (OCDR84).

Some students (11.5%) also found it difficult explaining the difference between a trait, a gene and an allele. Whereas a gene is a portion of DNA that determines a certain trait, an allele is a specific form of a gene. Genes are responsible for the expression of traits. Alleles are responsible for the variations in which a given trait can be expressed. However, students appeared confused over the differences. Excerpts are as follows:

> "An allele is a pair of genes located on the same locus on homologous chromosomes responsible for the same trait or character but producing different effects" (OCDR 31).

> "An allele is part of the gene. A gene is made of the dominant and recessive allele" (OCDR84).

Other students (4.2%) exhibited confusion in using what forms an allele to describe it. Scientifically an allele is a nucleotide sequence on a DNA/RNA molecule and not the possible outcome of fertilization. Excerpts are:

> "An allele is an alternative of the possible outcome of the cross of a male sex cell and a female sex cell" (OCDR22).

> "An allele is the structure formed from the crossing over of chromatids in meiosis" (OCDR24).

Item 10 sought to find out whether students had the conceptual understanding that each cell of an organism contains all the genes of that organism. For Item 10, 62.6% of students' explanations were in the domains of alternative conceptions and other conceptual difficulties. This is because 56.3% of students' explanations were alternative conceptions and 6.3% were other conceptual difficulties, while 34.4% had no idea of what an allele is.

For Item 10, 29.2% of students answered "Yes" to the statement "Does a muscle cell have only the genes needed to function as part of a muscle?" This means that 22.9% of students answered "No" to the statement, and 47.9%

answered neither "Yes" nor "No" to the statement. The differences between those with no idea and those who did not respond "Yes" or "No' is that some students did not respond yes or no but gave their explanations. As stated earlier, students' alternative conceptions and other conceptual difficulties on Item 10 can be seen as follows:

Alternative conceptions: Some students (43.8%) explained that each gene is specific to a cell. However, scientifically, each cell in an organism has all the genes of the organism necessary for proper functioning, since DNA is the same throughout all the cells. Excerpts of students' explanations are:

> "Yes, because each gene is specific to a cell or tissue or organ" (ACR 52).

> "Yes this is because the genes of the muscle cell were produced purposely for the functioning of the muscle cells as a muscle" (ACR 41).

Other students (13.5%) explained that a specific gene helps a specific cell perform its functions, and is thus the only gene found in that cell. However, scientifically, every cell in an organism has all the genes of that organism. Excerpts of students' explanations depicting this alternative conception are:

> "Yes, a cell must perform a specific function; if it is a muscle cell, then it has the genes to function as part of a muscle" (ACR 56). "

> "Yes. Because the genes in the muscle cell helps the muscle to function well" (ACR 93).

Other conceptual difficulties: Some students (2.1%) also had difficulties conceptualizing why a muscle cell does not have only the genes needed for functioning as part of a muscle. Thus, though they stated that the muscle cell has other genes of the organism (which is scientifically accurate, because each cell contains all the genes of an organism), their explanations indicated that they still had the conception that the cell contains some but not all genes. Excerpts of students' explanations include:

> "The muscle cell does not have only the genes needed to function. It also has the genes that distinguishes the genetic makeup of the body (the genotype). So apart from the genes needed to function it also has a gene for genetic makeup" (OCDR 04),
>
> "A muscle cell does not only have the genes needed to function because the nerve impulses which transmit nerve impulses cause movement and so does the bones which control the movement" (OCDR 10).

Other students (4.2%) who stated that the muscle cell had other genes apart from genes needed to function as part of a muscle found it difficult explaining their conceptions. Excerpts include:

> "Muscle cell does not have only the gene needed to function" (OCDR 87).
>
> "No. Because during contraction and relaxation of muscles different organelles also play an important role like mitochondrion" (OCDR 76).

Item 11 sought to find out whether students had the conceptual understanding that every cell has all the genes of an organism. For Item 11, all the students found it difficult to understand that the skin cell has a gene for eye colour (as well as all other genes of the individual organism). Also 70.7% of students' explanations were in the domains of alternative conceptions and other conceptual difficulties. This is because 68.7% of the explanations were alternative conceptions and 2.1% were other conceptual difficulties. 29.2% of students failed to express any idea in response to the question.

For Item 11, only 11.5% of students answered “Yes” to the statement “Does a skin cell have a gene for eye color?” This means that 46.9% answered “No” to the statement, and 41.7% answered neither “Yes” nor “No”. As stated earlier, the differences between those with no idea and those who did not respond “Yes” or “No’ is that some students did not respond yes or no but gave their explanations. As indicated earlier, students’ alternative conceptions and other conceptual difficulties on this item can be seen as follows:

Alternative conceptions: Students (68.7%) explained that every cell has a specific gene for a particular function, to the exclusion of other genes. However, scientifically, every cell has all the genes of the organism. Excerpts of students’ explanations include:

> “No, because every cell is specialized and has the specific gene combination for a particular function, hence it would have alleles for skin colour and the eye would have alleles for eye colour” (ACR03).

> “A skin cell has no gene for eye colour because the gene responsible for the colour of the skin is different from that of the colour of the eye” (ACR10).

Other conceptual difficulties: Students (2.1%) who said a skin cell has genes for eye colour found it difficult to explain why. These students stated that eye colour is polygenic, that is why it is contained in the skin cell. However, scientifically, every body cell (autosome) contains all the genes of an organism. Excerpts are:

"Yes. Eye colour is a polygenic trait, meaning it is determined by multiple genes" (OCDR64, OCDR65).

"Yes, this is because that gene gives the eye it original colour and absence of this gene causes problems" (OCDR72).

Item 12 sought to find out whether students understand the concept of allelomorphism, i.e. a gene exists in variant forms. For Item 12, 50% of students' explanations were in the domain of alternative conceptions and other conceptual difficulties. This is because 32.3% of students' explanations were alternative conceptions and 17.7% were other conceptual difficulties.

For Item 12, 53.1% of students responded "Yes" to the statement "Can there be different versions (forms) of a single gene?" This means that 7.3% of students answered "No" to the statement and 39.6% answered neither "Yes" nor "No". As stated earlier, the differences between those with no idea and those who did not respond "Yes" or "No' is that some students did not respond yes or no but gave their explanations. Students' alternative conceptions and other conceptual difficulties on this item can be seen as follows:

Alternative conceptions: Some students (11.6.0%) explained that genes contain different traits. However, scientifically, genes do not contain traits, but encode for proteins that are expressed as traits. The different traits that are observed, are as a result of the existence of allelic forms of a particular gene. An excerpt is:

"Yes, because genes contain different traits" (ACR65).

Other students (20.8%) explained that different forms of a gene exist for different characters in an organism. Scientifically, though, the different forms of a gene control the same inherited characteristic and thus are allelic forms of the same gene. Excerpts are as follows:

> "…Different forms of a gene control the different colours of the hair. Also, some will promote hair growth more than other genes for hair growth" (ACR 09).

> "Yes. Because there are different forms of a gene for different characters".

Other conceptual difficulties: Other students (17.7%) found it difficult conceptualizing how genes get to exist in different forms. Their explanations thus showed that they were not clear about how a gene can exist in more than one form. Excerpts are:

> "Yes. This is because, taking hair for example, some people have grey hair and at the same time black hair. Different gens control the different colours of hair. Also, some genes for hair will promote hair growth more than other genes for hair growth" (OCDR 09).

> "Yes. Because along the line some gene can be affected by external factors leading to the deformity of these genes and in these case it could happen that not all the genes would be affected. This means the same gene can exist in two forms" (OCDR 42).

Item 13 sought to find out whether students had the conceptual understanding that differences between siblings can be explained on the basis of allelomorphism, i.e. the existence and inheritance of different forms of a gene by progeny (or offspring). For Item 13, 79.2% of students' explanations were in the domains of alternative conceptions and other conceptual difficulties. This is because 60.4% of their explanations were alternative conceptions and 18.8% were other conceptual difficulties while 17.7% of them had no idea of reasons for the existence of differences between offspring of same parents.

Alternative conceptions: Some students (24.0%) explained that individual siblings of same parents have different genes. However, scientifically, siblings inherit the same genes from their parents, the differences between them being the result of siblings acquiring different forms of the same genes. Excerpts of students' explanations are:

> "This will happen because they actually have different genes which carry different chromosomes" (ACR 87).

> "The siblings will look different because the parental phenotype or genotype after meiosis undergoes random fertilization and different forms of genotype are produced and this results in different types of genes producing different looks" (ACR 10).

Other students (14.6%) explained that siblings inheriting dominant genes from father results in differences between them. An excerpt is:

> "Two siblings of the same parents may look different from each other because the dominant character or dominant gene trait from the father may affect either one of the siblings …" (ACR 08).

Still other students (21.9%) explained that siblings possessing a particular parent's genes to a 'high' degree bring about differences in them. However, scientifically, parental genes are not inherited in degrees (i.e. high, medium and low). An excerpt is:

"This is so because there may be dominance of a particular trait as compared to the other offspring. A sibling may possess heavily on one of the parents genes or hereditary material and the other may be having the hereditary material of the other" (ACR 39).

Other conceptual difficulties: Some students (11.5%) had difficulty explaining what it is in the different ova or spermatozoa that formed the individual siblings that result in their being different from each other. Excerpts of this conceptual difficulty include:

"This is because they did not develop from the same egg but were fertilized separately by different sperm as separate eggs, hence would not bear the same genotype and possible phenotype" (OCDR03).

"This is due to the random crossing of the gametes of the parents which can result to different characteristics of the offspring" (OCDR23).

"Fraternal siblings develop from a separate ovum being fertilized by a separate sperm and hence may have different DNA, different blood group and different phenotypic make up" (OCDR54).

Other students (7.3%) could not explain what occurs during the process of meiosis that results in genes being of different allelic forms. Allelomorphism could be as a result of mutation. Excerpts of students' responses typifying this conceptual difficulty are:

"Due to meiosis two siblings of the same parents may look entirely different. This occurs during a process called meiosis I where the chromosome pairs that are produced by both parents are fused to copy different characters and then transformed into the offspring" (OCDR60).

"This is possible because meiosis, which can cause a total differentiation in daughter cells can cause a resulting differentiation in the physiology of individuals" (OCDR71).

Item 14 sought to find out whether students had the conceptual understanding that a gene encodes the instruction needed for the production of a protein. For item 14, 42.7% of students' explanations were in the domains of alternative conceptions and other conceptual difficulties. This is because 39.6% of the explanations were alternative conceptions and 3.2% were other conceptual difficulties, whereas 36.5% of the students had no idea of the relationship between a gene and protein.

Alternative conceptions: Some students (22.9%) explained that genes are products of proteins and are proteins. However, scientifically, genes consist of nucleotides and not amino acids. Also, proteins are rather products of genes as genes encode the instruction for producing proteins. Excerpts of students' responses exemplifying this conception are:

"Genes are produced from proteins and are proteins" (ACR 05).

"A gene's make up is protein in nature. The gene is made up of many proteins" (ACR 12).

"Protein produce genes" (ACR 83).

Other students (6.3%) explained that a gene contains traits that code for a particular protein. However, scientifically, a gene encodes the instruction for the production of a protein whose expression results in a trait. Excerpts of this alternative conception are:

"The traits that code for a particular protein are contained in a gene" (ACR 71).

"A gene contains the traits that codes for a particular protein" (ACR 60).

Some other students (10.4%) also explained that a gene is formed out of protein synthesis. Scientifically, however, the end product of protein synthesis is a protein and not a gene. But a gene is involved in the process. An excerpt typifying this conception is:

> "The synthesis of the protein molecule helps in the translation stage of the DNA formation which forms a peptide bond that bears a set of instructions called the gene. Therefore, out of the protein synthesis a gene is formed" (ACR 08).

Other conceptual difficulties: Some students (3.2%) found it difficult explaining the relationship between a gene and protein. They simply tried to differentiate between the two. The following are excerpts:

> "A gene carries genetic information but protein aids in the metabolism of individuals" (OCDR 47).
>
> "Genes control a particular character or trait but protein does not control a character" (OCDR 30).
>
> "A protein is a polymer of amino acids and a very long chain but a gene is a very small structure containing alleles for the control of specific traits" (OCDR 09).

Categories of Students' Alternative Conceptions in Gene

In order to determine the types of alternative conceptions exhibited by students on the gene concept, once again the five categories of alternative conceptions outlined by the NRC and adopted by Adu-Gyamfi and Ampiah (2019) were employed. They are: Preconceived notions, Nonscientific beliefs, Conceptual misunderstanding, Vernacular misconception and Factual misconception. As with the chromosome and DNA concepts, 50 of the alternative conceptions in gene were randomly selected and categorized. The frequency of occurrences of each of the five categories is presented by Figure 5.

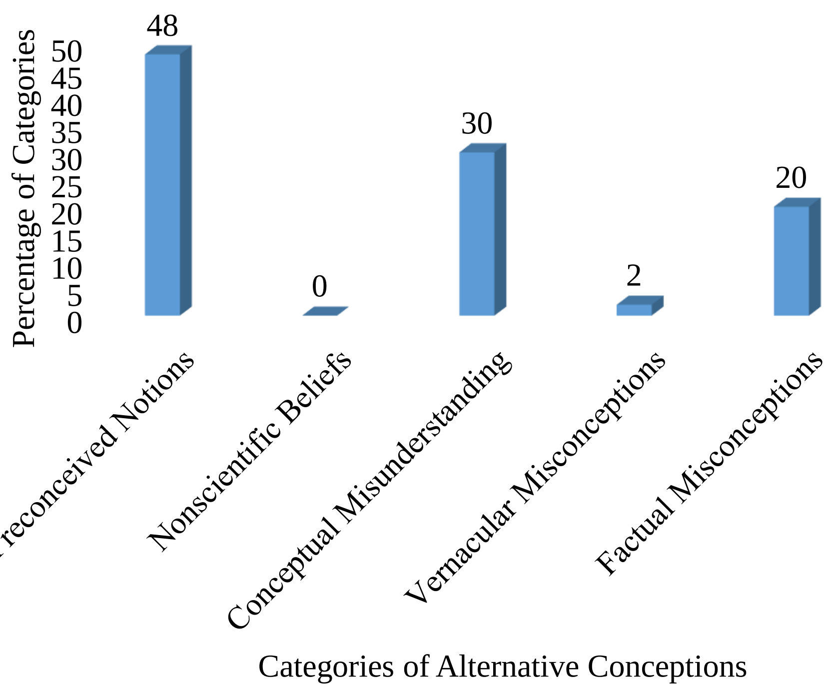

Figure 5: An illustration of categories of alternative conceptions on gene.

Source: Field data (Dzidzinyo, 2019)

The results from Figure 5 show that one of the five categories of alternative conceptions is absent from the alternative conceptions students had with the gene concept. Among the alternative conceptions, there was no nonscientific belief. The majority (48.0%) of students' alternative conceptions in gene were preconceived notions as students conceptions were based on everyday experiences. Some students' (16.0%) used the everyday experience that the gene is a particle. An excerpt is as follows:

> "A gene is a sort of particle located on a particular point on a larger structure known as a chromosome…" (ACR2).

Other students (32.0%) used the everyday conception that a gene is made up of protein. An excerpt is:

> "The gene is made up of protein, having its source from the chromosomes" (ACR06).

The next category of alternative conceptions that was well identified (30%) was conceptual misunderstanding as students' conceptions may have developed from science lessons which failed to help them confront their preconceived notions and nonscientific beliefs. Some students (2.0%) used the preconceived notion that phenotype or genotype undergoes random fertilization, resulting in the formation of different genes. The following is an excerpt of students' explanations in this category:

> "The siblings will look different because the parental phenotype or genotype after meiosis undergoes random fertilization and different forms of genotype are produced and this results in different types of genes producing different looks" (ACR 10).

Other students (12.0%) used the preconceived notion that alleles are characters found on genes. An excerpt is:

> "Alleles are characters that can be found on genes. Example: a gene for height may contain alleles of shortness or tallness" (ACR 05).

Other students (16.0%) also used the preconceived notion that genes take the colour of particular organs from parents, and that genes give colour to various organs. An excerpt is as follows:

> "No, this is because the skin has a particular gene which takes the colour of the skin from either parent. Also, the eye also has its own gene which gives its colour" (ACR 28).

The vernacular misunderstanding category of alternative conceptions was the least (2.0%) represented. Here students' conceptions of scientific words may have other meanings in everyday life. Some students (2.0%) used the everyday life meaning that traits are transferred from parents to offspring. An excerpt of students' explanation is as follows:

> "In a single cell there will be more of chromosomes because in the circulatory system only the combined structure which is the chromosome exists and performs its function of transferring traits" (ACR 10).

The fourth category, factual misconception, was also fairly (20%) represented. With this category, students' conceptions may have developed from false ideas that are learned in early ages but have not been challenged. Some students (2.0%) used the false idea that an allele is in a gene. The following is an excerpt of students' explanations typifying it:

> "An allele is located on a particular or specific loci of a chromosome which is responsible for the characteristics of an individual since it is in the gene" (ACR 08).

Other students (8.0%) used the false idea that a gene is the end product of protein synthesis. An excerpt is as follows:

> "The synthesis of the protein molecule helps in the translation stage of the DNA formation which forms a peptide bond that bears a set of instructions called the gene. Therefore, out of the protein synthesis a gene is formed" (ACR 08).

Other students (10.0%) also used the false idea that siblings inheriting dominant traits or otherwise results in their looking different from each other. An excerpt of students' explanations is as follows:

> "This is so because there may be dominance of a particular trait as compared to the other offspring. A sibling may possess heavily on one of the parents' genes or hereditary material and the other may be have the hereditary material of the other" (ACR 39).

The results show that students exhibited both scientific accurate and alternative conceptions in their responses together with other conceptual difficulties in responding to test items on chromosome, DNA and gene. In these response-types, students' alternative conceptions and other conceptual difficulties were more than the correct scientific conceptions. The results show that there are diverse categories of students' conceptions with respect to genetics (Haskel-Ittah & Yarden, 2018). With respect to alternative conceptions in chromosome, there are no preconceived notions and nonscientific beliefs, but conceptual misunderstanding, vernacular misconceptions and factual misconceptions. This means that, none of the students' alternative conceptions in chromosomes is influenced by what students experience in their daily lives nor things that are mythical. However, aspects of teaching and learning of science, communication of science concepts, and knowledge acquired in early stages of learning science that have not been challenged over the years and have persisted to current ages of the selected students, influence their alternative conceptions in chromosome concept. Thus, there are students' alternative conceptions with learning chromosomes and their sources are varied and related to the teaching and learning of biological concepts but not in myth and everyday experiences. For conceptual misunderstanding in chromosome, teaching and learning of biology at the SHS might have failed to help students confront their ideas that chromosomes are found in gene and DNA, genes contain 23 pairs of chromosome, and that there are twice as many chromosomes as there are genes. Biology educators and teachers, especially at the high school level, should re-look at their teaching approaches and adopt cognitive conflicting approaches (Franke et al., 2013) to help students overcome their alternative conceptions developed in the same biology lessons. For factual misconceptions, students seem to have developed false ideas of chromosome from some of their earlier lessons that: chromosomes are in the DNA, chromosomes are equated to DNA, and DNA molecules are folded into chromosome. These alternative conceptions of chromosomes are biology lessons-related at early stages of learning science and thus science teachers in general, and biology teachers in particular, should be careful to develop true conceptions of biology in teaching their students, and to help students avoid development of false ideas of chromosomes. Though there are not much of vernacular misconceptions of chromosomes as seen in this study, the few that were encountered could be attributed to the use of the term chromosome in areas other than biology lessons. For example mass media and social media platforms. For vernacular misconceptions, students learning that parents transfer structures to their children and that transfer is through blood circulation may not have been developed in science (biology) classrooms but from vernacular parlance that a person has it (i.e. a trait) in the blood. Students should be helped by biology educators and teachers to understand that there could be everyday uses of chromosome in socio-cultural context that may not have the same meaning as in science.

With respect to the DNA concept, the results show that there are no vernacular misconceptions and nonscientific beliefs but preconceived notions, conceptual misunderstanding and factual misconceptions are present. It seems that with the DNA concept, students' alternative conceptions are not influenced by words that mean different things in their everyday lives, as well as ideas from religious and/or mythical teachings. However, false ideas about scientific phenomena students might have learnt in their early years, as well as their everyday experiences that are contrary to scientific conceptions that were not challenged by classroom instruction did influence their alternative conceptions with the DNA concept. As such, there is the existence of students' alternative conceptions with learning the DNA concept, which are of different origins, but are all mostly as a result of perhaps the failure of science teachers to challenge such during science (specifically, biology) lessons in order to help students confront and restructure such into the correct science concepts (Duit & Treagust, 2003). For preconceived notions of the DNA concept, biology lessons at the SHS had failed to challenge students' everyday ideas that parents' traits are transferred to offspring, genes contain traits passed from parents to offspring, different cells have different functions and thus have different DNAs in the same organism. These alternative conceptions are subtle, and teachers may not be aware of their existence. Thus, science educators in general, and biology educators in particular should be aware of the existence of alternative conceptions of such nature that need to be addressed to ensure the smooth acquisition of science concepts, including the DNA concept (Duit & Treagust). Once they are aware, they should find ways and means to elicit those alternative conceptions and address them. For conceptual misunderstandings with DNA concept, teaching and learning of biology at the SHS failed to enable students challenge their everyday notions that DNA in different cells of an organism's body consists of different genes, different cells perform different functions so DNA contains instructions for performing different functions. These everyday notions could hinder development of conceptual understanding in DNA by students. Biology educators and teachers at the SHS level should first elicit these everyday notions and then adopt conceptual change approaches that will prompt cognitive conflict in students (Franke, Scharfenberger, & Bogner, 2013), leading to their becoming dissatisfied with the current conception and looking for more intelligible ones (Franke et al., 2013). For factual misconceptions with the DNA concept, students developed false ideas about DNA from previous lessons that DNA is made of proteins, and DNA is the information passed from parents to offspring. Since these are alternative conceptions linked to biology lessons students had at early stages of their science education, biology teachers should ensure that correct conceptions of biology concepts are developed in their students' cognitive structures right from the onset. Students also may have developed these preconceived notions from biology textbooks they use and thus, textbook writers must of necessity present the DNA concept right using detailed illustrations and analogies where appropriate (Akçay, 2016; Dikmenli, 2015).

With respect to the gene concept, the results indicate that all but one (i.e. nonscientific beliefs) of the five categories of alternative conceptions were present. This implies that with the gene concept, none of the students' alternative conceptions is influenced by religious ideas and myths. Rather, students' alternative conceptions are influenced by other experiences in daily living. These may be things related to science teaching and learning, communication of science concepts, knowledge acquired in early science education that have not been challenged, and have thus persisted right to their current level of education. For preconceived notions of the gene concept which are common among students, students used popular everyday experiences that the gene is a particle, and the gene is made up of protein, Since these are popular everyday experiences, biology teachers will do well to employ conceptual change approaches in their genetics lessons to ensure students' pre-instructional conceptual structures are fundamentally restructured in order to give room for understanding the intended knowledge (Duit & Treagust, 2003). For conceptual misunderstanding of the gene, students used the everyday notion that phenotype or genotype undergoes random fertilization leading to the formation of different genes, alleles are characters found on genes, and genes take the colour of particular organs from parents. Since these are everyday notions, SHS biology teachers can incorporate the use of concept cartoons in their genetics lessons to get students to engage in student-student dialogues to help them restructure their ideas appropriately (Joyce, 2009; Saloum & BouJaoude, 2017). For factual misconceptions in the gene concept, students use false ideas that they may have learned in early ages that an allele is in a gene, a gene is the end product of protein synthesis, and siblings inheriting dominant traits or otherwise, results in their looking different from each other. Since these are false ideas learned in early science education that have not been challenged, science educators and teachers who teach science to learners in their early ages should carefully help students develop the right conceptions from the very beginning of learners' education, using conceptual change approaches geared towards the creation of cognitive conflict in students to prompt them to restructure their pre-instructional conceptual structures to acquire the science concepts being taught (Duit & Treagust, 2003). The alternative conception category that is less common among students is vernacular misconceptions. Here students used the other meanings of scientific words in everyday life that traits are transferred from parents to offspring. Since everyday meanings of scientific words are concerned here, science teachers in general and biology teachers in particular should endeavour to help students switch appropriately between the everyday usage and the scientific meanings (Blown & Bryce, 2017).

It is also worthy of note that whereas alternative conceptions with regards to both the chromosome and DNA concepts are of three categories – Preconceived notions, Factual misconceptions and Conceptual misunderstandings – those of the gene concept are of four categories. The four categories include the three that are found to be common to both chromosome and DNA in addition to vernacular misconceptions. For all the three concepts, Nonscientific beliefs as a category of alternative conceptions is absent. Also, Vernacular misconceptions, except for the gene concept, are absent for both the chromosome and DNA concepts. The fact that all three concepts have preconceived notions, factual misconceptions and conceptual misunderstandings may be because they are peculiar to science concepts. This may be so as a study of redox reactions by Adu-Gyamfi and Ampiah (2019) also found the same three categories of alternative conceptions with the chemical concepts studied.

Generally, the results of this study show that the other conceptual difficulties students have with the three concepts – chromosome, DNA and gene

- in addition to the alternative conceptions were mostly present as students' inability to give clear explanations to response options they chose. In such instances students simply wrote yes/no or a simple phrase/statement denoting agreement or disagreement with the question. For some students, their other conceptual difficulties with the three concepts were present as uncertainty of facts. Since these other conceptual difficulties are merely confusion over facts learned, they can be overcome if teachers incorporate the use of audiovisual and/or visual representations of the concepts into their genetics lessons (Bada, 2016).

How often students use alternative conceptions and scientific conceptions to answer genetics questions

Research question 2 sought to compare the frequency with which students used scientific conceptions and their alternative conceptions of chromosome, DNA and gene in answering questions. To achieve this, students' responses on the achievement test (Appendix B) were categorized into four – SAR, ACR, OCDR, and NR. The frequency counts and percentages of the alternative conception responses (ACR) and the scientifically accurate responses (SAR) for all the items on the questionnaire that were used to ascertain students' conceptions on the three genetics concepts studied – chromosome, DNA and gene - were selected. Table 4 presents the results on the proportions of students' responses that were alternative conceptions and those that were scientific conceptions.

Generally, the results from Table 4 indicate that not all the responses of the 96 students were identified as scientifically accurate responses (SARs) and alternative conception responses (ACRs). This is because there were instances

Table 4: Percentage Usage of Scientifically Accurate Responses and Alternative Conception Responses in Genetics

Item	Number of Responses	SAR		ACR	
		f	%	f	%
9	58	30	31.3	28	29.2
10	57	3	3.1	54	56.3
11	66	0	0	66	68.8
12	47	16	16.7	31	32.3
13	61	3	3.1	58	60.4
14	58	20	20.8	38	39.6

SAR – scientifically accurate response; ACR – alternative conception response
Source: Field data (Dzidzinyo, 2019)

where some students' responses were neither identified as SARs and ACRs but were treated as no response and deleted, resulting in the differences in the numbers of responses under each item. The item with the highest percentage response 77 (80.2%) of SARs and ACRs out of the expected 96 responses was Item 8 and that with the least percentage response 45 (46.9%) of SARs and ACRs out of the expected 96 responses was Item 5.

From Table 4, it can be seen that it was only on Items 4 and 9 that the percentages of SARs were higher than the percentages of ACRs.

Item 9 sought to find out whether students had the scientific conception that an allele is a variant form of a gene, occupying the same position locus on paired chromosomes and controlling the same inherited characteristic. With this item, 60.4% of the expected 96 responses were identified as SAR (31.3%) and ACR (29.2%). Excerpts are as follows:

"An allele is just like a particular gene, just that it is some sort of an alternate form of that gene and hence controls that same character that gene controls only it has a different effect on it. E.g. Blue eye gene and green eye gene" (SAR 02).

"An allele is a different form of gene that occupies the same locus on the homologous chromosome and produce contrasting characters" (SAR 35).

"Alleles are characters that can be found on genes. Example: a gene for height may contain alleles of shortness or tallness" (ACR 05).

"An allele is an alternative of the possible outcome of the cross of a male sex cell and female sex cell" (ACR 22).

Item 10 sought to find out whether students had the scientific conceptual understanding that a muscle cell does not have only the genes needed to function as part of a muscle because each cell contains a complete copy of the organism's total genetic code. With this item, 59.4% of the expected 96 responses were identified as SAR (3.1%) and ACR (56.3%). Excerpts are as follows:

"A muscle cell will not have only the genes required to function as a part of a muscle because it will contain the same chromosomes as any other cell in the organism and subsequently the same genes and DNA molecules. The genetic makeup of an organism is same all over the organism's body" (SAR 02).

"No. This is because all cells in a mature organism have the same set of genes, but only a subset of those genes are turned on in any specific cell type" (SAR 71).

Of the number of SARs and ACRs, 94.7% were identified as alternative conceptions. Excerpts are:

> "Yes this is because the genes of the muscles were produced purposely for the functioning of the muscle cells as muscle" (41).
>
> "Yes, a cell must perform a specific function; if it is a muscle cell, then it has the genes to function as part of a muscle" (56).

This is an indication that most of the students' responses were alternative conceptions compared to scientific conceptions on whether or not a muscle cell has only the genes needed to function as part of a muscle.

Item 11 sought to find out whether students had the conceptual understanding that a skin cell has a gene for eye colour but the gene for eye colour is not expressed in the skin cell. With this item, no scientific conception was identified among students' responses. Thus, the number of SAR and ACR indicated under Item 11, were all alternative conceptions (68.8%). Excerpts are:

> "No, because every cell is specialized and has the specific gene combination for a particular function, hence it would have alleles for skin colour and the eye would have alleles for eye colour" (ACR 03).
>
> "No, because gene controls a specific trait in the organism. A skin cell will have genes to control the colour of the skin but not a gene for eye colour because it will have no function there" (ACR 09).
>
> "No, because a skin cell has it special gene other than the eye which is obviously of different forms" (ACR 39).

Item 12 sought to find out whether students had the conceptual understanding that the existence of allelomorphs (or alleles) presupposes that a single gene can have more than one version/form, as alleles are different versions of the same gene that produce distinct phenotypic effects. With this item, 49.0% of the expected 96 responses were identified as SAR (16.7%) and ACR (32.3%). Excerpts are as follows:

> "Yes. There can. This is the principle that brings about alleles. The presence of different versions of a gene determine what an organism will be like. For instance for eye colour, there are blue, brown, green, etc, all these are versions of the eye colour gene known as alleles" (SAR02).

> "Yes. The alternative forms of a gene are known as alleles. Each gene is made up of alleles and depending on whether these alleles are dominant or recessive, it determines the phenotype (physical) expression of that gene" (SAR07).

> "There can't be many versions or forms of a single gene because the gene is not able to exist on its own very much except in extraordinary situations" (ACR 10).

> "Yes, because there are different sub units of the DNA molecule that contains the gene" (ACR 20).

Item 13 sought to find out whether students had the conceptual understanding that two siblings of the same parentage will look different from each other since each sibling randomly inherits different versions of the same gene (i.e. alleles) from the parents. With this item, 63.5% of the expected 96 responses were identified as SAR (3.1%) and ACR (60.4%). Excerpts are as follows:

> "This is because they inherited different allele combination from their parents" (SAR 04).

"This is because the pair of alleles which combined to form their appearances were different though the alleles were from the same parents" (SAR 48).

"The siblings will look different because the parental phenotype or genotype after meiosis undergoes random fertilization and different forms of genotype are produced and this results in different types of genes producing different looks" (ACR 10).

"This will happen because they actually have different genes which carry different chromosomes" (ACR 87).

Item 14 sought to find out whether students had the conceptual understanding that genes contain information needed to make functional proteins. With this item, 60.4% of the expected 96 responses were identified as SAR (20.8%) and ACR (39.6%). Excerpts are as follows:

"A gene is a set of instructions that controls the formation of proteins" (SAR 41).

"Most genes contain the information needed to make functional molecules called proteins" (SAR 78).

"Genes are produced from proteins and are actually proteins" (ACR 05).

"A gene contains the traits that code for a particular protein" (ACR 60).

To explore the overall picture with regards to the frequency of usage of alternative conceptions and that of scientific conceptions in answering questions, individual students' usage of the four categories of responses were calculated. The results were then used to tease out the proportion of students' responses that were alternative conceptions and those that were scientific conceptions. Figure 6 presents the results of the overall proportion of students' responses over the four categories of responses. This was done for all the fourteen items that were used to ascertain students' conceptualisations of the three concepts – chromosome, DNA and gene.

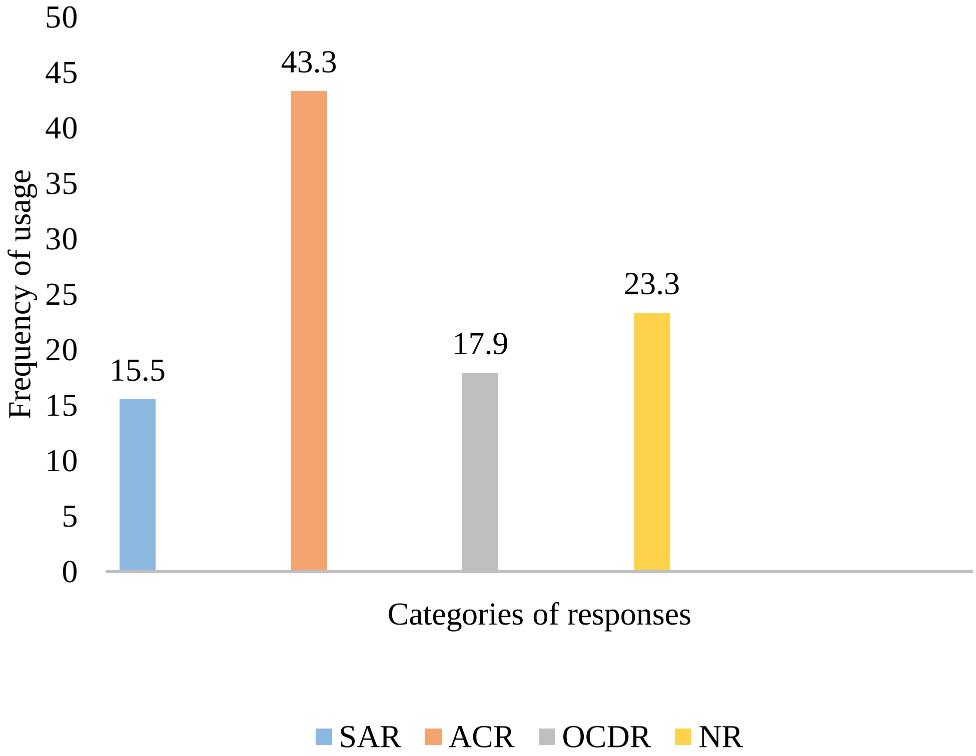

Figure 6: Illustration of proportion of usage of the four categories of responses on the SATG.

Source: Field data (Dzidzinyo, 2019)

Figure 6 shows that overall, students' usage of scientific conceptions and alternative conceptions in answering genetics question which is 58.8% was higher than the usage of each of the remaining two categories of responses (i.e. NR and OCDR). This means that more than half of the students' responses were in the domains of scientific conceptions and alternative conceptions. However, comparing the usage of scientific conceptions and alternative conceptions, it can be seen that there is a large difference between the proportions of students' usage of scientific and the alternative conceptions in answering questions on genetics. This is because responses in the alternative conception (43.3%) domain were almost three times more than responses in the scientific conception (15.5%) domain. It can thus be said that in answering genetics questions, the frequency of usage of alternative conceptions of the concepts studied is far higher than the usage of the scientific conceptions by students.

The results show that students use both alternative conceptions and scientific conceptions in responding to test items on genetics. However, students use alternative conceptions more often than scientific conceptions. This could be attributed to classroom teaching, textbooks, and everyday experiences (Sewell, 2002). Students have alternative conceptions in chromosome, DNA and gene as there is the likelihood that their teachers also have similar conceptions, for Driver and Bell, as cited in Mutimucuio (1991) reported that “teachers also bring their prior conceptions to learning situations” (p.46) which influence their way of interacting in classrooms and how students conceptualise the same concepts; and that students mirror their teachers’ conceptions. Textbooks are said to be sources of alternative conceptions that tend to be misleading to both teachers and students (Hershey, 2004; 2005) as they are among the commonly used effective teaching and learning materials. Science teachers in general, and biology teachers in particular must of necessity scrutinize the textbooks they use and recommend to their students for alternative conceptions, and use the ones that have little or no alternative conceptions. To be able to do that teachers must have the skills for undertaking content analysis, thus biology educators can include content analysis techniques in their repertoire of content given to teacher candidates (Dikmenli et al., 2009). Where everyday experiences lead to students developing alternative conceptions, teachers could, as a matter of caution, first try to elicit students' ideas of concepts to be taught and keep such in mind as they teach making a conscious effort to challenge those everyday experiences that may interfere with the smooth acquisition of the science concepts. Students using their alternative conceptions of chromosome, DNA and gene concepts more often than the science concepts may also imply that they find their alternative conceptions of the three concepts more plausible than the scientific conceptions as their everyday experiences were not reconciled with the scientific conceptions that were taught (Franke et al., 2013). In the absence of that reconciliation, the learners may not have been aware of the inadequacies of their conceptions, and as such were not prepared to be receptive to the scientific concepts (Duit, 2012; Duit et al., 2005; Gilbert & Watts, 1983). Biology educators and researchers are encouraged to design and develop teaching approaches that will help students overcome their alternative conceptions in genetics.

The results further show that generally students have more alternative conceptions of the gene concept than they have with chromosome and DNA concepts. This confirms what other studies have reported, that students tend to have many conceptual issues with the gene concept, resulting in their exhibiting incoherent understanding of the concept (Franke et al., 2013; Koksal & Akkaya, 2017; Lewis & Kattman, 2004; Lewis & Wood- Robinson, 2000). For instance, Lewis and Kattman (2004) found out that none of the 482 English high school students studied appeared to 'hold any coherent understanding …of the gene as a physical entity with a specific location (p. 201). However, the current study has been able to indicate the frequency with which students use their alternative conceptions of the gene as against the frequency with which they use the science conceptions taught in classrooms.

Senior High School Teachers Perception of Genetics, What Areas they Emphasise and How they Teach Genetics

Research question 3 sought to find out how senior high school teachers perceive, emphasise and teach genetics. Two instruments – Teachers' Questionnaire on their Teaching Practices, Challenges and Nature of Genetics, TQTPCNG (Appendix A) and Interview Guide for Teachers on Effective Teaching Practices for Genetics, IGTETPG (Appendix C) were used.

The results from the TQTPCNG and IGTETPG are presented in three sections as:

1. Teachers' perception of genetics
2. Areas teachers emphasise in genetics
3. Methods and strategies used by teachers in teaching genetics.

Teachers' perception of genetics

Items 16 to 20 of the teachers' questionnaire were used to answer questions on teachers' perception of genetics. Teachers were required to indicate the extent to which they agreed or disagreed with statements on perception of genetics given to them. The results are presented in Table 5.

The results show that generally teachers perception of genetics was slightly positive with a mean score of 3.2 out of 5 (SD=1.0). Majority of the teachers (70%) with a mean of 1.1 (SD = 0.5) strongly disagreed (10.0%) or disagreed (60.0%) with the statement that 'Genetics is an abstract subject'. It is therefore, not surprising that majority of teachers (80.0%) with a mean of 3.7

and SD= 0.7 agreed that Genetics has practical applications for addressing real life issues.

However, with a mean of 2.3 (SD=1.3) 75% of teachers strongly disagreed (30%) or disagreed (45%) that students naturally liked genetics. It is therefore, not surprising that 65% of teachers with a mean of 3.7 and SD=1.1 strongly agreed (15%) or agreed (50%) that teachers should give students prescriptive and sequential directions for learning genetics.

Interviews with teachers revealed that they appreciate the importance of students understanding how genetics is used in the real world. Some teachers explained that helping students to understand how genetics is used in the real world is important as it will enable students make informed decisions in selecting spouses in the future. Excerpts of their responses are as follows:

> "…it's important so that at least if in future they want to marry they will know certain things about their partner before they marry to prevent any further problem in future" (Teacher from school A).

> "…And then practically in terms of marrying how they can make informed choices and they seem to appreciate that a lot" (Teacher from school C).

Others explained that getting students to understand the importance of genetics is beneficial as it helps them to understand how traits and certain disease conditions are inherited from parents. The excerpt is:

> "I think genetics should be one of the very interesting subjects any student should study. It gives them the opportunity to understand how they inherit certain traits. So if they have a particular condition they get

Table 5: Teachers' Perceptions of Genetics as a Subject (N=20)

Item	Statement	SD		D		U		A		SA		Mean	SD
		n	%	n	%	n	%	n	%	n	%		
16	Genetics is an abstract subject	2	10	12	60	0	0	3	15	3	15	2.7	1.3
17	Genetics is a formal way of representing the real world	0	0	2	10	2	10	16	80	0	0	3.7	0.7
18	Genetics has practical applications for addressing real life issues	0	0	1	5	2	10	17	85	0	0	3.8	0.5
19	Students naturally like genetics	6	30	9	45	0	0	4	20	1	5	2.3	1.3
20	It is important for teachers to give students prescriptive and sequential directions for learning genetics	0	0	5	25	2	10	10	50	3	15	3.6	1.1

Where SD = Strongly Disagree; D = Disagree; A = Agree; SA = Strongly Agree; maximum score =4; minimum score =1

Source: Field data (Dzidzinyo, 2019)

to know how it came about. If they need to manage it then they should be in a better position to manage it. Like the sickle cell anaemia. So after taking them through, I let them know it's not their fault, it is the gene they inherited. But they can do a lot by studying a lot about the condition. It's just a condition it doesn't mean they are different" (Teacher from school B).

Also, a teacher explained that it is important for students to understand the importance of genetics as it helps them apply genetics in everyday life situations. The teacher explained:

"It's very important. When you're learning and you can associate what you learn in the classroom with whatever is happening in the world it makes the lesson very interesting. For instance, in teaching sex determination, we stress on the fact that it is the father who determines the sex of the child not the mother. So any father who wants to divorce the wife because she has been giving birth to only girls, we tell the students it means the father is illiterate. So they enjoy biology because they relate what happens in the real world to what they are learning" (Teacher, School C).

Areas teachers emphasise in genetics

Research question 3 further sought to find out what areas are emphasized frequently by teachers in their genetics lessons. Teachers were given four areas to respond to on how frequent they used those areas. Their responses are presented by Table 6.

The results on Table 6 indicate that generally, about 45% teachers frequently emphasized all the four areas presented on the questionnaire in most of their lessons. This is because the calculated overall mean score was 2.5 (SD = 0.7) and there were three areas that about 45% teachers emphasized in most of their lessons (i.e. Items 27, 28 and 29) and one area that they emphasized in few of their lessons (i.e. Item 26).

After the teachers' responded to the questionnaire items, there was a follow up interview with the IGTETPG. This was done to ascertain whether teachers' responses on the interview were in alignment with what they do in class. Upon interacting with the four teachers using interviews, it was clear that some of them emphasized the use of student-student interactions whereas others went for whole class interactions with teacher. For instance a teacher explained that he uses argumentation to get students to interact with one another. He explained thus:

> "…So it gets them a little bit more argumentative… I believe in generating arguments in class. The more people argue, the more they bring up facts to disprove or overcome another person's point…So it's important you allow some people to speak in the class for their colleagues to also correct their mistakes. Once it's an argument then it means somebody is wrong…" (Teacher, School D).

Since the teacher asks questions that gets the students to argue with each other, and he allows students to bring up facts that disprove colleagues' earlier arguments, it implies that the teacher employs student-student interactions. This

Table 6: Areas Teachers Emphasize Frequently in their Genetics Lessons (N=20)

Item	Statement In your genetics lessons, which of these areas do you emphasize the most?	ANL		FL		ML		AEL		Mean	SD
		n	%	n	%	n	%	n	%		
26	Work on problems for which there is no standard method of solution	1	5	10	50	9	45	0	0	2.4	0.6
27	Write explanations about what was observed	0	0	10	50	9	45	1	5	2.6	0.6
28	whole class interaction with the teacher	2	10	9	45	7	35	2	10	2.5	0.8
29	students interacting with one another	1	5	9	45	9	45	1	5	2.5	0.7

Where ANL = Almost No Lesson; FL = Few Lessons; ML = Most Lessons; AEL = Almost Every Lesson;

Maximum score =4; Minimum score = 1.

Source: Field data (Dzidzinyo, 2019)

confirms what teachers reported on the questionnaire. This is because from Table 6, teachers reported that they frequently emphasized students interacting with each other in most of their lessons.

The same teacher further explained that he emphasized whole class interaction with teacher if arguments among students prove inconclusive. He stated:

> "…So if the argument cannot be settled then it will come up for the whole class to settle it and then as a teacher you try to settle that misconception…or you put that discussion in context…

In effect, this teacher is saying that he follows student-student interactions up with student-teacher interactions or whole class interactions with teacher when student-student interactions have to be concluded appropriately. Another teacher explained how she lays emphasis on whole class interaction with teacher through the use of scenarios. She explains:

> '…So I explain, then ask 'has it gone down well?' You get them saying 'yes'. Then I'll give a scenario and call a student to come and represent whatever I've said on the board, genetically. So you get them doing it; may be wrong, and I say 'Is it correct?' Some will say 'yes/no'…" (Teacher, School C).

This teacher accordingly, interacts with the whole class by first getting individual students to give responses to questions and then asking other members in the class to comments on the answers giving by colleagues. Thus, once again, the two teachers' responses on the interview confirm what teachers reported on the questionnaire: teachers frequently emphasize whole class interaction with teacher in most of their lessons.

How teachers teach genetics

Research question 3 further sought to find out how teachers teach genetics. Teachers were supplied with seven areas of teaching methods and strategies to respond to. The proportion of teachers' choices of the response options to the seven items are presented on Table 7.

The results from Table 7 indicate that generally teachers use the listed techniques very often in their genetics lesson. This is because the calculated overall mean score was 2.5 (SD = 0.7) and in five instances (Items 31, 33, 34, 35 and 36) teachers used the listed teaching methods and strategies very often, whereas in two instances (Items 30 and 32) teachers used the listed teaching methods and strategies often.

On Item 31, 95% of teachers, at a mean of 2.6 out of 5 (SD = 0.7) used teacher-guided student practice very often. Of the 95% teachers, 35% often used teacher-guided student practice in their genetics lessons.

On Item 33, 80% of teachers, at a mean of 2.5 (SD = 0.9) used student independent practice very often. Of the 85% teachers, 55% often used student independent practice in teaching genetics. This is an indication that 15% of the teachers almost always used student independent practice and only 5% rarely used it in their genetics lessons.

On Item 34, 80% of teachers at a mean of 2.70(SD =0.9) very often used tests and quizzes in teaching genetics. Of the 80% teachers, 55% often used tests and quizzes in teaching genetics. This is an indication that only 15% of the teachers almost always used tests and quizzes and none of them rarely used it in teaching genetics.

Table 7: Teaching Methods and Strategies used in Teaching Genetics

Item	Statement	R		O		VO		AA		A		Mean	SD
		n	%	n	%	n	%	n	%	n	%		
30	homework review	3	15	9	45	8	40	0	0	0	0	2.3	0.7
31	teacher-guided student practice	1	5	7	35	12	60	0	0	0	0	2.6	0.6
32	re-teaching and clarification of content/procedures	1	5	12	60	7	35	0	0	0	0	2.3	0.6
33	student independent practice	1	5	11	55	5	25	3	15	0	0	2.5	0.8
34	tests and quizzes	0	0	11	55	5	25	3	15	1	5	2.7	0.9
35	teacher demonstrations	0	0	7	35	11	55	2	10	0	0	2.8	0.6
36	students demonstrations	0	0	10	50	10	50	0	0	0	0	2.5	0.5

Where R = Rarely; O = Often; VO = Very Often; AA = Almost Always; and A = Always
Source: Field data (Dzidzinyo, 2019)

On Item 35, 90% of teachers at a mean of 2.75 (SD = 0.639) very often used teacher demonstrations in their genetics lessons. Of the 90% teachers, 35% often used teacher demonstrations in their genetics lessons. This indicates that only 10% almost always used teacher demonstrations and none of them rarely used it in teaching genetics to their students.

On Item 36, all the teachers at a mean of 2.50 (SD = 0.513) very often used student demonstrations in teaching genetics. 50% of the teachers often used student demonstrations in their genetics lessons. This gives an indication that none of the teachers almost always used student demonstrations and none rarely used it in teaching genetics to their students.

On Item 30, 85% of teachers at a mean of 2.25 (SD = 0.716) often use homework review in teaching genetics. Of the 85% teachers, 40% very often used homework review in teaching genetics. This gives an indication that none of the teachers almost always used homework review and only 15% rarely used homework review in teaching genetics to their students.

On Item 32, 95% of teachers at a mean of 2.30 (SD = 0.571) often used student demonstrations in their genetics lessons. Of the 95% teachers, 35% very often used student demonstrations in teaching genetics. This gives an indication that none of the teachers almost always used student demonstrations and only 5% rarely used it in teaching genetics to their students.

After the teachers' responded to the questionnaire items, there was a follow up interview with the IGTETPG. This was done to ascertain whether teachers' responses on the questionnaire with regards to the methods and strategies they employ in teaching genetics were in alignment with what they do in class. Upon interacting with four of the teachers using the interview, it became clear that teachers used different methods and strategies for teaching genetics. While some stated they use a 'mixture' of methods, others stuck to one method. And these either confirm or disconfirm the responses from the questionnaire. For instance, one teacher explained that she uses drills to help students learn how to write genotypes of individuals. She explains:

> "…So what I do is that I take them through drills. Supposing we have homozygous tall man and a heterozygous short woman how would you represent it? So we keep doing that till they are used to writing those things. Then we show them how to bring the genes together to write them as one unit then we go into the table" (Teacher, School C).

From the explanation, it can be seen that the teacher drills the students as they practice representing information in genetics algorithms. This does not confirm what teachers reported on Table 7, that they very often used teacher-guided student practice.

The same teacher (i.e. teacher from School C) indicated that she usually used lecture method for explaining concepts, but follows up with blackboard illustration and the use of scenarios where students are called upon to participate. She explains:

> "…from the beginning you have to do a little bit of the lecture method when you are explaining to them. Afterwards illustration. Blackboard illustration is very good. So I switch over to blackboard illustration. Then I switch over to the students. I involve them. So I give you a scenario…"

From this teacher's explanation, it is obvious that she presents information (lecture) interspersed with 2-D illustrations. Once again, this does not confirm teachers' responses on Table 7 that they use student independent practice very often.

Another teacher emphatically stated she uses demonstration method as it is good. She explains:

> "I do demonstrate…I mean the demonstration method is good…" (Teacher, School B).

This teacher confirms that teachers use teacher demonstrations in teaching genetics, though she was not clear in how the demonstration is done. This confirms teachers' responses on the questionnaire, as from Table 7, teachers indicated they use teacher demonstrations very often.

One teacher explained that she uses the question-and-answer technique. She explains:

> "They do participate. Because I give them a lot of questions as in giving them a scenario just to determine which of the … I mean genetic diagram for them to cross just to find out if the father is maybe a carrier of this, the mother is this, what is the possibility that the child will be that? And they've been trying themselves. I give them questions" (Teacher from School A).

Another teacher indicated that she uses what she calls step-by-teaching, where she explains, asks questions and introduces scenarios, in order to get the students to participate fully. This teacher also uses the question-and-answer technique. She explains:

> "…So normally I do a step by step teaching. So I explain, I ask, has it gone down well? You get them saying, yes. Then I'll give a scenario, I call a student to come and represent whatever I've said on the board, genetically. So you get them doing it may be wrong, and I say, is it correct? Some will say yes/no. okay those who agree…Why is it correct? Why is it wrong? Speak…Yeah. Those who disagree. Then eventually we will resolve it. So we keep doing that. And then we get a lot of them engaging. Some will also be coming up with questions they've seen and they've not been able to answer. At times I give them a hint then they go, solve come back" (Teacher from School B).

Thus, these two teachers use the question-and-answer technique which is not included among the seven strategies on Table 7. This implies that teachers use teaching and learning techniques in addition to those captured by the questionnaire. This is not surprising as the list on Table 7 is not exhaustive, and teachers are resourceful enough to use a variety of methods, strategies and techniques that they find relevant during a lesson.

Another teacher uses reading assignment to get students to participate in her genetics lessons, though she does not indicate whether or not she reviews what students are assigned to read. She explains:

> "First, after teaching every topic, the students are told to read on the next lesson before coming. So before they come for the next class they would have had prior knowledge about the objective for the next lesson. Then two, trying to explain what happens in the real world and relating them

> to the theory learnt makes them enjoy genetics than other topics in Biology".

Thus, the teacher gives homework, and reviews it during the day's lesson. This confirms the responses on Table 7 that teachers often use homework review in their genetics lessons.

Another teacher uses group work to get all students to participate. He explains:

> "Yes, everybody will participate… questions that are going to be answered you put them in groups and then not simple questions that will demand A, B or C answer but questions that would generate some thinking and debate in the group. So you get people contributing. When I group students what I normally do is place questions in the class and it will be answered on group basis so whoever I choose to call should be able to answer on behalf of the group and so group members ensure that everyone participates so that any member I will call will be able to answer. And of course I know the weak ones in the class so if they can be sure that I am going to call the weak person then everybody puts in his best to ensure that the weakest person in the group can say something" (Teacher from School D).

This teacher's use of group work is laudable but does not confirm that teachers use re-teaching and clarification of content/procedures as a technique in teaching genetics. However, as has been pointed out earlier, the list given teachers was not exhaustive. Thus, the interview was also intended to bring to the fore other methods, strategies and techniques teachers use in their genetics lessons and this is an example of that.

Another revealing issue that came up during the interviews was the use of instructional materials in teaching genetics. Teachers indicated they use a variety of instructional materials in their lessons. For instance a teacher explained that she uses the blackboard to illustrate concepts in addition to real life scenarios as instructional materials, though the blackboard is not an instructional material. She explains:

> "Normally I'll do a lot of blackboard illustrations then I will give real life examples. Like oh eerrm in your family do you all look the same? Then you get somebody telling you no, no three of us we are different but one looks particularly like our grandparent. So we use the real life… and someone will say aahh yes that's why our sister is fair and then we are dark…"

Another teacher explained that she used coloured beans in teaching Mendel's first law. She explains:

> "Sometimes under probability of a gene occurring in the first filial or second filial generation we use different colours of beans. We make them mix the beans up and they will be picking the genes in pairs as Mendel's first law suggests that the factors that control characteristics are internal and in pairs so sometimes we use these beans (Teacher, School C).

Obviously, this teacher uses the beans analogically, whereby she asks the students to consider each coloured bean as a gene. In that sense students are made to visualise what otherwise they cannot, in order to be able to conceptualise the concept understudy.

The same teacher alluded to the use of other technological devices and models for teaching genetics. She explains:

> "These times there are a lot of technological devices you can use, a lot of videos that you can show, then you use beads on threads to show chromosomes and a whole lot of things. Models are there in the lab" (Teacher, School C).

Another teacher also explained that he used pictures in textbooks as instructional materials as they were readily available for students. He explains:

> "We sometimes use pictures in textbooks, because that one is available to a lot of people. You can have a look at it even in their private time" (Teacher, School D).

Another teacher uses videos, models and drawings in teaching genetics. He explains:

> "And then when it comes to processes that should follow a particular sequence, if you have a video of it, it makes it stick better. It makes the understanding really go far, because it will direct something that they may not really understand. So sometimes you allow them to read over it and then you sort of play the video and then they begin to ask questions on the text you read that does not really connect too well with the video. There are times when you arrange models for them to also put together. Or by drawings …" (Teacher, School B)

The results show that teachers have a neutral perception towards the teaching of genetics, and generally did not perceive it as an abstract subject. This finding that genetics is not abstract does not support the works of some researchers who studied genetics education at the upper secondary level (Knippels, 2002; Knippels et al., 2005; Altunoølu & Seker, 2015) which indicate that genetics is abstract. The differences between the findings of this current study and that of these researchers may be as a result of the different levels of education at which the studies were conducted. As to why teachers in the current study perceive genetics as not abstract, the teachers gave the reason that they consider genetics to have practical applications for addressing real life issues.

Teachers perceive genetics as a formal way of representing the real world and as such would want to make sure students follow certain rules and guidelines in studying genetics. The nature of genetics is such that one may not succeed in its study without following some conventional rules in learning certain genetic mechanisms (Smith & Wood, 2016). A student must of necessity learn the step-by-step guide for doing this. This view of the teachers may be what informs their perception that genetics is a practical and structured guide for addressing real situations, and that it is important for teachers to give students prescriptive and sequential directions for learning genetics.

The interaction with the teachers bringing forth that teachers appreciate the importance of students understanding the uses of genetics in the real world may be the underlining factor informing the selection of the teaching methods and strategies for teaching genetics to students. Yet, as this study has shown, students exhibit a number of alternative conceptions and other conceptual difficulties with genetics concepts, which may mean that even though teachers know that students benefit from a clear understanding of genetics concepts, they may have challenges with using the appropriate methods and strategies to ensure students develop the acceptable scientific conceptions.

Teachers placing emphasis on student-student interactions and whole class student-teacher interactions in most of their lessons means that they encourage active learning in their lessons with the use of two-way interactions: student-student interactions and teacher-student interactions. These types of interactions are known to help students restructure their ideas appropriately if used well (Saloum & BouJaoude, 2017). However, this study's finding that students use their alternative conceptions more often than they do the scientific conceptions indicate that the two types of dialogues may not have been used effectively enough.

The results that teachers use some teaching methods and strategies very often in their genetics lessons such as homework review, demonstrations, student independent practice, teacher-guided student practice, and question-and-answer technique mean that teachers vary their methods and strategies for teaching genetics. These methods are not only confirmed from the questionnaire, but interactions with the teachers revealed same.

The results show that the teachers know and use what qualifies as teaching learning materials. This is because they mentioned teaching learning materials they used for their lessons such as models, textbook pictures and videos. However, students exhibiting alternative conceptions in chromosome, DNA and gene could suggest that teachers' use of instructional materials and strategies failed to challenge students' prior conceptions which they find to be more plausible than the correct conceptions taught (Duit & Treagust, 2003).

Teachers claim to use different teaching strategies in trying to help students learn genetics. While some give scenarios and follow up with questions that are intended to rope in all students, some give reading assignments which are supposed to give students prior knowledge for subsequent lessons. In this way the teachers expect students to bring what they read on their own to bear on the lessons. This could have been laudable and would have had a positive impact on students' conceptions, however this is not the case in this study as there appears to be a missing link between what teachers claim to practice and students' conceptions in genetics.

Effectiveness of Conceptual Change Approach used for helping students' Conceptual Development of Chromosome, DNA and Gene

The fourth research question sought to determine the effectiveness of the conceptual change approach used for teaching the three genetics concepts. To achieve this, a class of 14 students were exposed to a conceptual change teaching approach – the O-D-R conceptual change approach. The students were pretested and postested using the SATG and scored. Students' conceptions on the pretest and the posttests were compared. Only their scientifically accurate responses on both tests were considered. The results of the percentage scores on each test item are presented on Figure 7.

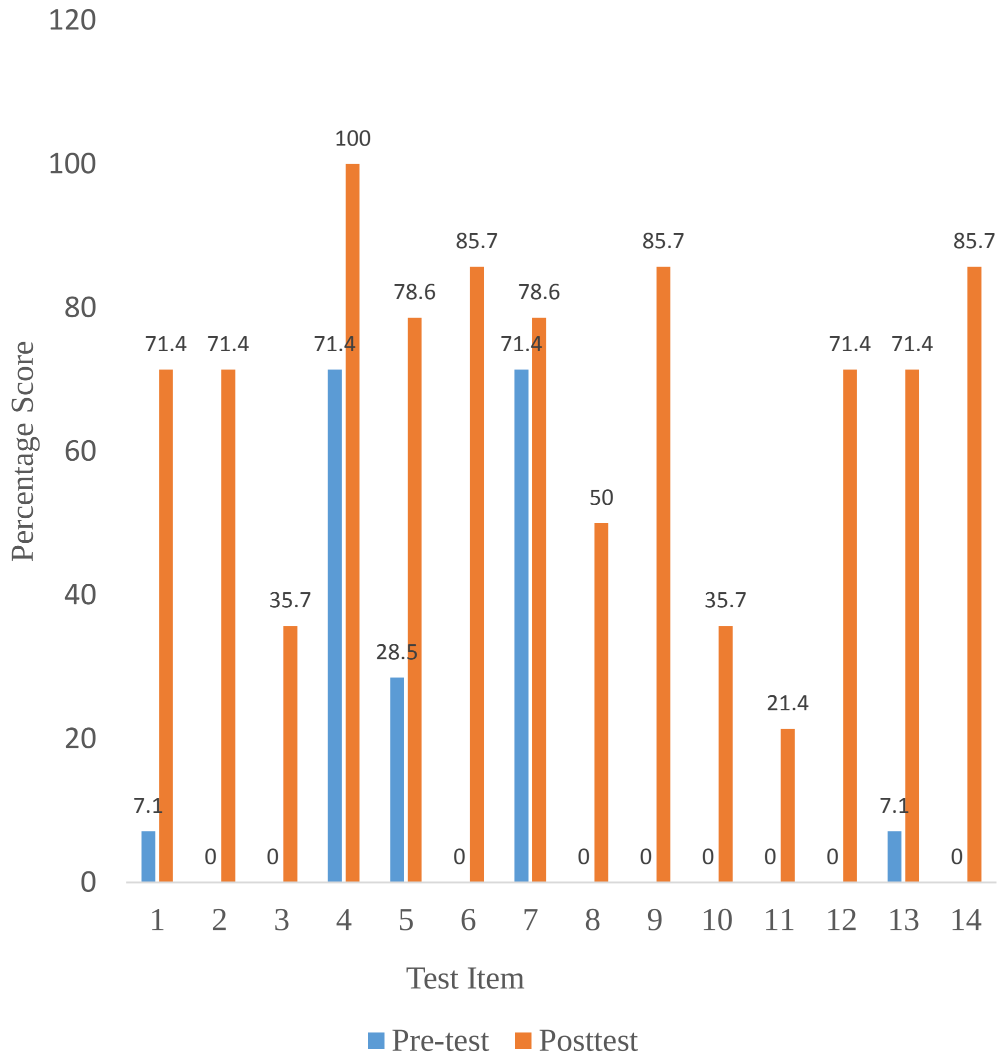

Figure 7. Illustration of students' percentage score in the pre-test and post-test on the three genetics concepts.
Source: Field data (Dzidzinyo, 2019)

The results from Figure 7 indicate that in the pre-test, not all students scored on all the items. On nine of the items (Items 2, 3, 6, 8, 9, 10, 11, 12 and 14) the score was zero. That is none of the students scored on any of these items on the pretest. It was only items 4 and 7 that 71.4% of students got the items correct.in the pretest. For the remaining three items (i.e. Items 1, 5 and 13), less than 50% of students got those items correct. On the other hand, in the post-test, , most of the students (71.4%) got the correct answer for most of the items on the three genetics concepts (Items 1, 2, 4, 5, 6, 7, 9, 12, 13 and 14). It was only on three of the items that less than 50% of students got the answer correct (Items 3, 10 and 11), and 50% students got the answer correct on Item 8 on the posttest. However, on Item 4 all the students scored full marks. The improvement in the students' post-test scores implies that teaching the three genetics concepts with the O-D-R conceptual change approach appears to have helped students conceptualize the concepts appropriately. From Figure 7, of the nine items on which no student scored any mark on the pre-test, the majority of the items (Items 9, 10, 11, 12 and 14) were on the gene concept. Three of the items (Items 2, 6 and 8), were on the DNA concept. Only one of the items (Item 2), was on the chromosome concept.

To further explore effectiveness of the O-D-R conceptual change approach, interactions were made with the students before and after each lesson. It became clear that they had benefited in diverse ways leading to the acquisition of the accepted conceptions of the three concepts studied. Based on the students' accounts of how the O-D-R lessons benefited them, it can be said that the intervention was, to a large extent, effective. This is attributable to the varied methods and strategies, as well as the different activities and resources used. Thus the intervention helped achieve the intended learning outcomes. The students had expectations before each lesson and these were met after the lessons. For instance, a student explained at the beginning of the lessons that he expected to have a clear mental idea of the three concepts. He stated:

> "I expect to have a clear picture of a chromosome, DNA and gene … when I hear any of the three terms, I want to be able to recall how each looks like" (Student 3).

Another student expected to understand all the three terms. He explained:

> "I try to read ahead of class. I tried reading about chromosome, DNA and gene and could not understand on my own. So I want to …understand what the three terms mean" (Student 7).

Other students wanted to be able to differentiate between the terms. The following are excerpts of what they said:

> "I want to understand the differences between the terms if any…" (Student 11).
>
> "Are there differences between the terms? I don't know and I want to find out …" (Student 9).
>
> "I wonder if the gene is not the same as DNA. Is there a difference, may be the lesson will make it clear for me…" (Student 1).

The lessons on chromosome, DNA and gene using the O-D-R teaching approach helped students have a clear picture of the three genetics concepts. This came out of the interactions with students after the lessons. Excerpts of students' explanations are:

> "Because of the videos, pictures and diagrams we were shown, I think I have a clear picture of the terms" (Student 3).
>
> "I think the use of the activities where we were made to tie thread around lime fruits, relate the parts of the zipper to DNA and cut pieces of it to represent genes, made me get a clear picture of the three terms" (Student 14).
>
> "When you compared the parts of the cassette to chromosome, DNA and gene, I got the differences between the three terms clearly" (Student 9).

However, one student was clear on all but the gene concept. He explained:

"On the whole, I think I'm ok. But I still am not very clear on what the gene is…" (Student 5).

Students enjoyed the lesson for various reasons and repeatedly remarked that they wished they were taught biology that way all the time. Excerpts of their expressions include:

"I enjoyed the lessons. I wish we are taught biology this way. It will make us understand things better" (Student 1).

"The videos and diagrams made things very clear. I think our teachers should be using them to teach us" (Student 2).

"I wish our teachers will teach using similar materials. It will make biology very interesting. To me the lessons were very good" (Student 4).

Students felt that concepts were clear to them because not much content was included in each of the lessons. They explained:

"I think because the content was not too much, things were clear" (Student 6).

Students felt that the teacher did not rush through the lessons, and they were thus able to follow. An excerpt is:

"The teacher did not rush through the lessons. I was able to follow everything that was taught" (Student 8).

Other students explained that the concepts became clear to them when they were made to share and challenge each other's ideas. An excerpt is:

"Because we were made to share and challenge each other's ideas, I think I now have a clear picture of the three terms …" (Student 2).

The fourth research question further sought to find any conceptual change that was experienced by the students as a result of the O-D-R conceptual change approach used to teach them. To that end, individual students' conceptions expressed on the pre- and post-tests were compared for each of the three concepts – chromosome, DNA and gene. Excerpts of their explanations on both tests are used with codes assigned to each student's pre- and post-test responses. For instance, for student one, his response on Item 1 on the pretest is coded $PR1_{01}$, whereas his response on Item 1 on the post-test is coded $PO1_{01}$. His explanations for Item 2 on the pre- and post-tests are coded $PR2_{01}$ and $PO2_{01}$ respectively.

Table 8 presents conceptual changes in students' learning of the chromosome, DNA and gene as a result of the use of the O-D-R conceptual change approach. The results from Table 8 indicate that generally students who exhibited conceptual difficulties on the pre-test overcome their difficulties on the post-test.

For instance, on the chromosome concept, student 1 had the alternative conception that "DNA contains chromosome, and therefore DNA is bigger than chromosome" ($PR2_{01}$). However, on the post-test his response "A chromosome is larger than a DNA molecule because a DNA molecule forms part of a chromosome" ($PO2_{01}$) indicated a change in conceptual understand. This is because the chromosome is formed from a condensation of the DNA molecule by means of packaging proteins such as histones packing the DNA tightly at prophase II of mitosis. Thus, as he rightly answered on the posttest, the DNA molecule is part of a chromosome

Table 8: Conceptual Change in Students' Learning Resulting from O-D-R Intervention

Concept (Items)	Responses	
	Pre-test	Post-test
Chromosome (2, 4, 5, 7)	DNA contains chromosome, and therefore DNA is bigger than chromosome (PR201).	A chromosome is larger than a DNA molecule because a DNA molecule forms part of a chromosome ($PO2_{01}$).
	No idea ($PR2_{06}$)	A chromosome is larger than a DNA molecule since a DNA molecule is found in a chromosome ($PO2_{06}$)
	DNA is smaller than chromosome as it is found in gene which is found in the chromosome ($PR2_{14}$).	A DNA molecule is a subset of a chromosome. A chromosome is larger than a DNA molecule. Although a chromosome contains one DNA molecule it has lots of histones attached to it making it dense ($PO2_{14}$).
	No idea ($PR4_{08}$).	No. This is because in the first place, a chromosome is not contained in a gene. The chromosome contains strand of DNA which contains genes ($PO4_{08}$).
	No idea ($PR4_{12}$).	No, a gene is not made of chromosomes… Chromosomes contain DNA molecule with a lot of histones and a DNA contains lots of gene ($PO4_{12}$).
	DNA is a material found in the nucleus of the cell which contains chromosomes which are genetic materials passed on from parent to child during reproduction ($PR5_{01}$)	A molecule of DNA packed by a packaging protein known as histone make up chromatin which make up chromosome ($PO5_{01}$).
	They are both involved in cell division and reproduction ($PR5_{08}$).	DNA is found in the chromosome. The chromosome contains a molecule of DNA that is held together or packed by packaging proteins called histones. The DNA molecule is what makes up the chromosome ($PO5_{08}$).
	No idea ($PR7_{10}$).	There would be more of genes. This is because a single gene contains several chromosomes and each chromosome contain DNA and each DNA contains thousands of gene ($PO7_{10}$).
	No idea ($PR7_{03}$).	There would be more genes than chromosomes. Genes are sections on DNA which is found in a chromosome. As a result, genes are shorter in length than chromosomes ($PO7_{03}$).

Table 8: (Continued)

Concept (Items)	Responses	
	Pre-test	**Post-test**
DNA (6,8)	Genes contain DNA strands ($PR6_{09}$).	A DNA is a molecule which consists of several nucleotides. The nucleotides consist of a pentose sugar, a phosphate group and a nitrogenous base, which are lettered A (Adenine), T (Thymine), C (Cytosine) and G (Guanine).Three or more of these bases is what is known as the gene. That is the gene is a section of the DNA ($PO6_{09}$).
	No idea ($PR6_{07}$).	A gene is a section of DNA while DNA is a double helix structure made up of several nucleotides ($PO6_{07}$).
	Yes DNA in a single skin cell is different from DNA in a single muscle cell (PR809)	No. All DNA in any cell of the body of a particular organism is the same (PO809)
	Yes, DNA in a single skin cell is different from DNA in a single muscle cell (PR814)	No, the DNA is roughly same in any part of the body. No two cells have different DNAs. All cells in the body… have similar DNA (PO814).
Gene (1, 9, 10, 11, 12, 13, 14)	Genes are a part of the nucleus of the cell that are the inheritable characteristics that can be transferred from parent to offspring. (PR106).	A gene is a strand or section of DNA which codes for the production of proteins (PO106)
	Genes are substances found in the chromosome. They carry traits from parents to offspring (PR114).	Gene is a fraction of the DNA. It contains code that are used to prepare proteins in the body. They contain different protein recipes. (PO114).
	Genes are structures found in the DNA which can be located in the nucleus of a cell and they transfer characteristics or traits from a parent to its offspring (PR109).	A gene is a section or portion of a DNA that codes for a particular protein. They can be as small in length as three letters (PO109).
	Alleles are chromosomes that contain traits of an organism (PR909).	An allele is an alternative form of the same gene (PO909).

Table 8: (Continued)

Concept (Items)	Responses Pre-test	Post-test
	No idea (PR9$_{05}$).	An allele is simply an alternative form of a gene. Or, a different form of a gene (PO9$_{05}$).
	No idea (PR10$_{02}$).	Yes. The unique function of a muscle cell from the other cells of the body is brought about by structural gene in a muscle cell that brings about its unique function as part of a muscle (PO10$_{02}$).
	Yes. (No explanation) PR10$_{06}$.	Yes, the genes in each DNA are modified for a specific purpose (PO10$_{06}$).
	No idea (PR10$_{12}$).	No. It doesn't have genes needed to function only as part of a muscle although it may be specialized. It contains other gene but just that it makes use of the one it needs for efficient functioning (PO10$_{12}$).
	No idea (PR11$_{03}$).	No! A skin cell has genes for producing different pigments of the skin. Due to this the genes in the skin cells cannot produce any proteins for eye colour (PO11$_{03}$).
	No. (No explanation) PR11$_{07}$.	The skin cells have genes for eye colour but cannot read meaning into the genes. Since genes are found on DNA and DNA in all parts of an organism are the same, then the skin cells can have genes for eye colour (PO11$_{07}$).
	No. (No explanation) PR1114	Yes it does. But the gene for eye colour is recessive (it has been masked by the skin colour gene). It only makes use of the gene for skin colour more than the other genes (PO1114).
	No idea (PR1205).	Yes, and they are called allelomorphs (allele). This is why the physical characteristics (phenotype) of each person differs (PO1205).
	Yes. An allele is the alternative form of a gene (PR1208).	No this is because different genes contain different codes to carry out specific tasks (PO1208).
	No idea (PR1210).	Yes there can be many versions of a single gene. These versions of the gene are represented as allelomorphs (PO1210).

Table 8: (Continued)

Concept (Items)	Responses: Pre-test	Post-test
	They obtain genes from the different parents ($PR13_{01}$).	This is because the two siblings inherited the same genes from their parents but of different forms. This explains the term allele ($PO13_{01}$).
	The DNA in their blood may be different ($PR13_{07}$).	The two siblings may have inherited different forms of the same gene. Since the form of a gene determines its structure and function, different forms will mean different looks ($PO13_{07}$).
	No idea ($PR13_{11}$).	Two siblings of the same parents would have the same DNA but different genes even if they are twins. They have different alleles (versions) of their genes which makes them both different ($PO13_{11}$).
	No idea ($PR14_{04}$).	A gene codes for the type of protein to be produced ($PO14_{04}$).
	No idea ($PR14_{08}$).	The gene is a code for the production of proteins. Proteins are produced due to a particular code of a gene in the DNA ($PO14_{08}$).
	No idea ($PR14_{12}$).	A gene has the recipe for protein synthesis. All proteins are built depending on the codes carried by a gene. The shape and size determines the proteins function and structure (PO1412).

Source: Field data (Dzidzinyo, 2019)

On the DNA concept, student 9 expressed an alternative conception on the pre-test that "Genes contain DNA strands" ($PR6_{09}$). However, on the post-test he had had a conceptual change as borne out by his response: "A DNA is a molecule which consists of several nucleotides…the gene is a section of the DNA" ($PO6_{09}$).

On the gene concept, student 7 expressed an alternative conception on the pre-test that siblings from the same parents will look different because "The DNA in their blood may be different" ($PR13_{07}$). However, on the post-test, he demonstrated a change in his prior conception by stating thus: "The two siblings may have inherited different forms of the same gene. Since the form of a gene determines its structure and function, different forms will mean different looks" ($PO13_{07}$).

The results from Table 8 also show that students who gave incomplete responses such as giving only yes or no responses, on the post-test gave clear and scientifically accurate responses. A case in point is student 7. On the pre-test in response to Item 11 which asked whether a skin cell has a gene for eye colour, he only wrote "No" without any explanation. Of course the answer was an alternative conception. However, on the post-test, he gave the response that indicated he had clearly had a conceptual change. The response was: "The skin cells have genes for eye colour but cannot read meaning into the genes. Since genes are found on DNA and DNA in all parts of an organism are the same, then the skin cells can have genes for eye colour" ($PO11_{07}$). Clearly, though the lessons used as the intervention did not cover regulation of gene expression, this student has a firm grasp of the basis for saying that yes, a skin cell has gene for eye colour – "…DNA in all parts of an organism are the same…" He also added his own constructed knowledge, that the skin cell "…cannot read meaning into…" the eye gene. In other words the regulation mechanism does not allow for the expression of the eye colour gene in the skin cell.

The results from Table 8 further show that all students who expressed no idea (i.e. non-responses) on the pre-test generally had a fair idea of what was being asked for on the post-test. As a matter of fact, there was only three non-responses on the post-test. These were from only one student – student 4 – on Items 10, 8 and 7. However, a few of the responses from the students who expressed no ideas on the pre-test but gave responses to the same items on the post-test were faulty. For instance, students 8 and 10 exhibited conceptual difficulties on the post-test. Student 8 made the statement "No. This is because in the first place, a chromosome is not contained in a gene. The chromosome contains strand of DNA which contains genes" ($PO4_{08}$). Stating that "…chromosome contains strand of DNA" is faulty. This is because each molecule of DNA contained in a single chromosome consists of two strands of DNA joined to each other to form the classic DNA double-helix (double stranded DNA). Student 10 also exhibited a similar conceptual difficulty with the following response to Item 7: "There would be more of genes. This is because a single gene contains several chromosomes and each chromosome contain DNA and each DNA contains thousands of gene" ($PO7_{10}$). A single gene does not contain several chromosomes. Rather, genes have their loci on a chromosome. Also to say that a single gene contains several chromosomes and each chromosome contains several DNA and each DNA contains thousands of genes is contradictory and clearly indicates that the student was not thinking clearly.

To further explore the effectiveness of the O-D-R conceptual change approach, explanations of students taught with the O-D-R conceptual change approach were compared with explanations of students at the first phase of the study who were not taught with the O-D-R conceptual change approach. Their explanations depicting their conceptions after having been taught the three concepts – chromosome, DNA, gene – were used. Explanations of students who were not taught with the O-D-R conceptual change approach have been labelled as NODR with the item number and a number subscript indicating the particular student who gave that explanation. For instance, if student number 5 gave the selected explanation on Item 7, the label will be NODR7_{05}. In a similar vein, explanations of students taught using the O-D-R conceptual change approach are labelled as ODR with the item number and a number subscript indicating the particular student. Thus ODR8_{02} means that the explanation is for Item 8 from student number 2 who was taught with the O-D-R conceptual change approach. Table 9 presents the explanations from the two groups of students on the three concepts – chromosome, DNA and gene. The explanations are subsequently compared.

Table 9. Explanations of Students Taught with the O-D-R Lessons and Students Taught without the O-D-R Lessons

Concept (Items)	Explanations	
	Non-O-D-R Students	O-D-R Students
Chromosome (2, 4, 5, 7)	DNA molecule is a set of grouped chromosomes hence DNA molecule may be larger than chromosomes ($NODR2_{29}$).	A chromosome is larger than a DNA molecule because a DNA molecule forms part of a chromosome ($ODR2_{01}$).
	The chromosome is much bigger than a single DNA molecule as the DNA is the building block for the chromosome. That is the chromosome is just a pack of various strands of DNA ($NODR2_{02}$).	A chromosome is larger than a DNA molecule since a DNA molecule is found in a chromosome ($ODR2_{06}$)
	A chromosome is relatively smaller than a DNA molecule. This is because a chromosome is made of a single strand but a DNA is made of a double strand ($NODR2_{22}$).	A DNA molecule is a subset of a chromosome. A chromosome is larger than a DNA molecule. Although a chromosome contains one DNA molecule it has lots of histones attached to it making it dense ($ODR2_{14}$).
	One gene contain many chromosome ($NODR4_{86}$).	No. This is because in the first place, a chromosome is not contained in a gene. The chromosome contains strand of DNA which contains genes ($ODR4_{08}$).
	Yes, because gene carries chromosomes from parents which are more than one ($NODR4_{93}$).	No, a gene is not made of chromosomes… Chromosomes contain DNA molecule with a lot of histones and a DNA contains lots of gene ($ODR4_{12}$).
	A chromosome is made up of many DNA molecules … ($NODR5_{12}$).	A molecule of DNA packed by a packaging protein known as histone make up chromatin which make up chromosome ($ODR5_{01}$).
	DNA is a very long strand of genetic material. A part of it is used for the formation of a chromosome ($NODR5_{09}$).	DNA is found in the chromosome. The chromosome contains a molecule of DNA that is held together or packed by packaging proteins called histones. The DNA molecule is what makes up the chromosome ($ODR5_{08}$).

Table 9: (Continued)

Concept (Items)	Explanations	
	Non-O-D-R Students	O-D-R Students
	… because a gene is made up of two chromosomes. As a result about twice as many chromosomes as genes will be found in a single cell ($NODR7_{06}$).	There would be more of genes. This is because a single gene contains several chromosomes and each chromosome contain DNA and each DNA contains thousands of gene ($ODR7_{10}$).
	… One gene contains more chromosomes and therefore the existence of a gene means the number of chromosomes will double … ($NODR7_{27}$).	There would be more genes than chromosomes. Genes are sections on DNA which is found in a chromosome. As a result, genes are shorter in length than chromosomes ($ODR7_{03}$).
DNA (6, 8)	DNA are long strands of protein molecules that take part in cell division … ($NODR6_{28}$).	A DNA is a molecule which consists of several nucleotides. The nucleotides consist of a pentose sugar, a phosphate group and a nitrogenous base, which are lettered A (Adenine), T (Thymine), C (Cytosine) and G (Guanine).Three or more of these bases is what is known as the gene. That is the gene is a section of the DNA (ODR609).
	DNA is a very specific traits that one has which is very unique from others, but gene are the characteristics the one picks from birth" ($NODR6_{86}$).	A gene is a section of DNA while DNA is a double helix structure made up of several nucleotides (ODR607).
	Because skin cell will show a different characteristic from a muscle cell. So the information in either DNA's should be different" ($NODR8_{18}$).	No. All DNA in any cell of the body of a particular organism is the same (ODR809)
	...DNA coding in the skin is programmed to call for proteins which will produce more skin cells. This same idea applies to the single muscle cell" ($NODR8_{01}$).	No, the DNA is roughly same in any part of the body. No two cells have different DNAs. All cells in the body… have similar DNA (ODR814).

Table 9. (Continued)

Concept (Items)	Explanations	
	Non-O-D-R Students	O-D-R Students
Gene (1, 9, 10, 11, 12, 13, 14)	A gene is a particle located on a particular point on a larger structure known as a chromosome…" $(NODR1_{02})$.	A gene is a strand or section of DNA which codes for the production of proteins (ODR106)
	A gene is a molecule which expresses a particular characteristic or trait due to the nature of the allele it possesses" $(NODR1_{07})$.	Gene is a fraction of the DNA. It contains code that are used to prepare proteins in the body. They contain different protein recipes. (ODR114).
	Gene is a unit on the chromosome that is responsible for the transfer of characteristics or features from parents to offspring" $(NODR1_{25})$.	A gene is a section or portion of a DNA that codes for a particular protein. They can be as small in length as three letters $(ODR1_{09})$.
	An allele is a different form of gene that occupies the same locus on the homologous chromosome and produce contrasting characters $(NODR9_{35})$.	An allele is an alternative form of the same gene $(PO9_{09})$.
	Alleles are characters that can be found on genes…$(NODR9_{22})$	An allele is simply an alternative form of a gene. Or, a different form of a gene $(PO9_{05})$.
	Yes, because each gene is specific to a cell or tissue or organ" $(NODR10_{52})$.	Yes. The unique function of a muscle cell from the other cells of the body is brought about by structural gene in a muscle cell that brings about its unique function as part of a muscle $(ODR10_{02})$.
	Yes, a cell must perform a specific function; if it is a muscle cell, then it has the genes to function as part of a muscle" $(NODR10_{56})$.	Yes, the genes in each DNA are modified for a specific purpose $(ODR10_{06})$.
	Yes this is because the genes of the muscle cell were produced purposely for the functioning of the muscle cells as a muscle" $(NODR10_{41})$.	No. It doesn't have genes needed to function only as part of a muscle although it may be specialized. It contains other gene but just that it makes use of the one it needs for efficient functioning $(ODR10_{12})$.

Table 9: (Continued)

Concept (Items)	Explanations	
	Non-O-D-R Students	O-D-R Students
	No, because every cell is specialized and has the specific gene combination for a particular function, hence it would have alleles for skin colour and the eye would have alleles for eye colour" (NODR11$_{03}$).	No! A skin cell has genes for producing different pigments of the skin. Due to this the genes in the skin cells cannot produce any proteins for eye colour (ODR11$_{03}$).
	A skin cell has no gene for eye colour because the gene responsible for the colour of the skin is different from that of the colour of the eye" (NODR11$_{10}$).	The skin cells have genes for eye colour but cannot read meaning into the genes. Since genes are found on DNA and DNA in all parts of an organism are the same, then the skin cells can have genes for eye colour (ODR11$_{07}$).
	Yes. Eye colour is a polygenic trait, meaning it is determined by multiple genes" (NODR11$_{64, 65}$).	Yes it does. But the gene for eye colour is recessive (it has been masked by the skin colour gene). It only makes use of the gene for skin colour more than the other genes (PO11$_{14}$).
	Yes, because genes contain different traits (NODR12$_{65}$).	Yes, and they are called allelomorphs (allele). This is why the physical characteristics (phenotype) of each person differs (PO12$_{05}$).
	Yes. This is because, taking hair for example, some people have grey hair and at the same time black hair. Different genes control the different colours of hair. Also, some genes for hair will promote hair growth more than other genes for hair growth (NODR12$_{09}$).	No this is because different genes contain different codes to carry out specific tasks (PO12$_{08}$).
	Yes. Because along the line some gene can be affected by external factors leading to the deformity of these genes and in these case it could happen that not all the genes would be affected. This means the same gene can exist in two forms (NODR12$_{42}$).	Yes there can be many versions of a single gene. These versions of the gene are represented as allelomorphs (PO12$_{10}$).
	This will happen because they actually have different genes which carry different chromosomes" (NODR13$_{87}$).	This is because the two siblings inherited the same genes from their parents but of different forms. This explains the term allele (PO13$_{01}$).

Table 9. (Continued)

Concept (Items)	Explanations	
	Non-O-D-R Students	O-D-R Students
	The siblings will look different because the parental phenotype or genotype after meiosis undergoes random fertilization and different forms of genotype are produced and this results in different types of genes producing different looks" ($NODR13_{10}$).	Two siblings of the same parents would have the same DNA but different genes even if they are twins. They have different alleles (versions) of their genes which makes them both different ($PO13_{11}$).
	Two siblings of the same parents may look different from each other because the dominant character or dominant gene trait from the father may affect either one of the siblings …" (NODR13 08).	Two siblings of the same parents would have the same DNA but different genes even if they are twins. They have different alleles (versions) of their genes which makes them both different ($PO13_{11}$).
	This is so because there may be dominance of a particular trait as cocmpared to the other offspring. Genes are produced from proteins and are proteins" (NODR1405).	A gene codes for the type of protein to be produced (ODR1404).
	The traits that code for a particular protein are contained in a gene" (NODR1471).	The gene is a code for the production of proteins. Proteins are produced due to a particular code of a gene in the DNA (ODR1408).
	The synthesis of the protein molecule helps in the translation stage of the DNA formation which forms a peptide bond that bears a set of instructions called the gene. Therefore out of the protein synthesis a gene is formed" ($NODR14_{08}$).	A gene has the recipe for protein synthesis. All proteins are built depending on the codes carried by a gene. The shape and size determines the proteins function and structure ($ODR14_{12}$).

Source: Field Data (Dzidzinyo, 2019)

As evident above, students taught with the O-D-R conceptual change approach (non-O-D-R students) generally used the scientific conceptions in their explanations of the three genetics concepts, whereas students taught without the O-D-R conceptual change approach gave explanations that generally express alternative conceptions and other conceptual difficulties. For instance, with the chromosome concept, non-O-D-R student 29 explained that chromosome is smaller than DNA because a molecule of DNA is a set of grouped chromosomes. However, a DNA molecule is a polynucleotide and not a set of grouped chromosomes. A single DNA molecule, rather, is condensed into a chromosome. Thus, making the chromosome bigger in size (i.e. thicker) than a DNA molecule. This scientific concept about the difference in size between a chromosome and a DNA was aptly explained by O-D-R student 1 as: "A chromosome is larger than a DNA molecule because a DNA molecule forms part of a chromosome". Another non-O-D-R student explained the difference in size between a chromosome and DNA in terms of the number of strands each is made of. According to the student, the chromosome is single stranded whereas DNA is double stranded. However, it is a molecule of DNA packed with packaging proteins that forms a single chromosome. Also, with regards to structure, it is the DNA which is double stranded, the chromosome is not described in terms of strands. O-D-R students on the other hand, explained that the chromosome is larger than DNA as the DNA forms part of a chromosome ($ODR2_{01}$, $ODR2_{14}$, $ODR2_{08}$).

Non-O-D-R students expressed the alternative conception that many chromosomes are contained in a gene ($NODR4_{86}$). However, scientifically the locus of a gene is on a chromosome and not vice versa. O-D-R students expressed the correct conception by explaining that chromosomes rather bear genes, as: "No, a gene is not made of chromosomes … Chromosome contains a DNA molecule with a lot of histones, and a DNA contains lots of genes" ($ODR4_{12}$). The O-D-R student's explanation went even further to give details regarding the relationship between a chromosome and a gene by explaining that a chromosome contains a DNA which in turn contains genes. This was missing from the non-O-D-R students' explanations. This is an indication that the O-D-R students had a better understanding of the chromosome concept.

Still on the chromosome concept, whereas non-O-D-R students have the conception that a chromosome consists of a number of DNA molecules, and that it is formed from a part of a DNA strand ($NODR5_{12}$), O-D-R students explained that chromosome consists of a molecule of DNA packed by packaging proteins ($ODR5_{01}$, $ODR5_{08}$). Once again, the O-D-R students had the concept right. This is because scientifically, a whole DNA, which is double stranded, is tightly packed by proteins, condensing it into a chromosome.

With regards to the DNA concept, a similar scenario can be seen from Table 9. For instance, non-O-D-R students explained the composition of DNA as: "DNA are long strands of protein molecules that take part in cell division …" ($NODR6_{28}$). This explanation expresses the alternative conception that DNA is composed of amino acids. However, scientifically, DNA consists of nucleotides which are made up of a nucleoside and a phosphate group. The non-O-D-R students' counterpart (i.e. ODR students), on the other hand explained thus: "A DNA is a molecule which consists of several nucleotides. The nucleotides consists of a pentose sugar, a phosphate group, and a nitrogenous base …" ($ODR6_{09}$).

Still on the DNA concept, non-O-D-R students' explanations implied that the DNA is a specific trait that makes individuals unique and genes are characteristics – "DNA is a very specific trait that one has which is very unique from others, but genes are the characteristics one picks from birth" ($NODR6_{86}$). However, scientifically a trait is the manifestation of a gene product that is coded for by the DNA. Thus, DNA is not a trait, neither is a gene a characteristic. On the other hand, O-D-R students gave explanations that were better conceptually – "A gene is a section of DNA while DNA is a double helix structure made up of several nucleotides" ($ODR6_{07}$).

Furthermore, non-O-D-R students expressed the alternative conception that DNA in a particular autosome is programmed to call for proteins for producing that cell – "DNA coding in the skin cell is programmed to call for proteins which will produce more skin cells. This same idea applies to the single muscle cell" ($NODR8_{01}$). However, scientifically, DNA is same in all autosomes of an organism, and thus has codes (genes) for all the different proteins necessary for the proper functioning of the individual. The O-D-R students' explanations, comparatively were better conceptually, as they expressed the scientific conception – "…DNA is roughly same in any part of the body. No two cells have different DNAs. All cells in the body have similar DNA" ($ODR8_{14}$).

On the gene concept, once again, O-D-R students' explanations were conceptually better than non-O-D-R students' explanations. For instance, whereas non-O-D-R students expressed the idea that alleles are characters found on genes – "Alleles are characters that can be found on genes …" ($NODR9_{22}$), O-D-R students expressed the scientific conception that an allele is a variant form of a gene – "An allele is simply an alternative form of a gene. Or a different form of a gene" (ODR9$_{22}$). The O-D-R students' version is scientifically accurate.

Still on the gene concept, whereas non-O-D-R students explained that a skin cell does not have the eye colour gene (NODR11$_{10}$), thereby expressing the alternative conception that each cell contains only the gene necessary for its functioning, O-D-R students explained that skin cells have genes for eye colour but cannot read meaning into the eye colour genes (ODR11$_{07}$). The O-D-R students' conceptions are scientifically accurate, since in every somatic cell of an organism, the DNA sectioned into genes, is the same, meaning that each cell contains all the genes of an organism.

The results from research question 4 that students demonstrated conceptual change in their prior knowledge on the post-test, that students' expectations are met, and that students' conceptions of the three concepts were generally scientifically accurate, is an indication that the O-D-R lessons were effective in helping students' to construct the correct conceptual understanding of the three genetics concepts – chromosome, DNA and gene. The O-D-R lessons are developed from conceptual change approaches having the basis in constructivism. It is a three-stage instructional strategy (made up of orientation, discovery and restructuring). The results show that students' conceptual understanding of the three genetics concepts were far better than those taught without the O-D-R conceptual approach. This is evidenced by the enhanced scientific conceptions demonstrated by the students on the post-test (Gal et al as cited by Adu-Gyamfi et al, 2020). This enhanced scientific conception could be as a result of the use of the O-D-R conceptual change approach. This is because it first elicited students' prior conceptions and proceeded to expose them to various activities that were intended for them to discover many of the basic ideas for understanding the three concepts. It also further exposed them to various visuals, audiovisuals and analogical realia that helped students concretize the concepts learned. Students also had the added opportunity to consciously interact with one another as well as interact with the teacher or facilitator. Thus it can be said that this novel O-D-R teaching approach was effective in helping students' acquire the scientific conceptual understanding of the three basic genetics concepts. Not only is the O-D-R effective, in helping students develop scientific conceptions, but it also meets their expectations. The students' expectations to have a clear picture of the three terms, to understand the meanings of the terms, and to be able to differentiate between the terms, are met. Since the students mention specific aspects of the lessons (use of videos, pictures, diagrams, analogies, and student-student interactions) that helped them understand the concepts, it can be said that the O-D-R instructional approach was effective in helping students acquire the scientific conceptions of the three genetics concepts and that biology educators and teachers should use approaches that are conceptual change oriented in teaching biological concepts.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter presents a summary for the study. It also gives a conclusion for the study and makes recommendations for educational policy and practice. It concludes with three suggestions for further research.

Summary

The study was undertaken to explore SHS students' conceptual understanding in three basic genetics concepts; - chromosome, DNA and gene. This became necessary because students at the SHS level had learning difficulties in the three basic genetics concepts. Four research questions were raised to guide the study. A triangulation convergence design model of the mixed methods approach was adopted to collect data for the study. The study was conducted in the Cape Coast Metropolis where a multistage sampling technique was used to sample 96 SHS 3 students, 14 SHS 2 students, and 20 Elective Biology teachers.

Three research instruments were used to collect data for this study. They were Students' Achievement Test on Genetics (SATG), Teachers' Questionnaire on their Teaching Practices, Challenges and Nature of Genetics (TQTPCNG), and Interview Guide for Teachers on Effective Teaching Practices for Genetics (IGTETPG).

The study employed a mixture of quantitative and qualitative research methods in the collection of data. The quantitative data consisted of the teachers' responses to items on the teachers' questionnaire (TQTPCNG) indicating their attitudes, beliefs, opinions and practices in relation to teaching and learning of genetics, and students' scores on the students' achievement test (SATG). The qualitative data, on the other hand, were obtained using the interview guide (IGTETPG), and students' achievement test explanations.

Key findings

1. (a) Alternative conceptions on the chromosome were Conceptual misunderstandings, Vernacular misconceptions and Factual misconceptions. Some of the conceptual difficulties students had with the chromosome concept included confusion about the relative sizes of chromosome and gene, as well as chromosomal numbers of different organisms. There was also difficulty in understanding that each chromosome consists of one DNA molecule.

   (b) Alternative conceptions with the DNA concept were preconceived notions, Factual misconceptions and Conceptual misunderstandings. Some conceptual difficulties exhibited by students included confusion about the relationship between DNA and gene.

   (c) Alternative conceptions with regards to the gene concept exhibited by students were preconceived notions, Conceptual misunderstandings, Factual misunderstandings and Vernacular misconceptions. The conceptual difficulties exhibited included difficulty conceptualizing the gene in terms of its composition, location and role in heredity.

2. Students used their alternative conceptions more often than the scientific conceptions in learning chromosome, DNA and gene.

3. Senior high school teachers' perception of genetics was slightly positive with a mean score of 3.2 out of 5 (SD=1.0). Senior high school teachers place

emphasis on student-student interactions and whole class interaction with teacher in most of their lessons implying that they encourage active learning in their lessons with the use of interaction. Senior high school teachers use a variety of teaching methods and strategies very often implying that teachers vary their methods and strategies for teaching genetics. However, teachers disconfirm some of their selected teaching strategies (such as student independent practice and teacher-guided student practice) they use in teaching and brought out new ones (such as drills and the use of teaching learning resources).

4. The O-D-R conceptual change approach used was effective as it resulted in major changes in students' conceptual understanding of the three concepts – chromosome, DNA and gene; and also met students' expectations in learning the chromosome, DNA and gene concepts

Conclusion

Much attention has been given to research into the teaching and learning of genetics as it is a predominantly challenging topic for both teachers and students. This study explored Ghanaian SHS elective biology students' conceptual understanding of *chromosome*, *DNA* and *gene* and developed an instructional strategy to address students' alternative conceptions and conceptual difficulties.

The findings on alternative conceptions and other conceptual difficulties are consistent with similar research findings (Knippels, 2002; Knippels et al, 2005; Altunoølu & Seker, 2015) that students have alternative conceptions and other conceptual difficulties with genetics that affect their understanding. However, whereas the existing literature only identify the individual alternative conceptions students have with the genetics concepts, the current study, has contributed to literature that the common categories of alternative conceptions in genetics are conceptual misunderstanding and factual misconceptions and that there are no nonscientific beliefs as students' alternative conception in learning chromosome, DNA and gene. Other conceptual difficulties were due to students' confusion over the concepts.

The findings on the frequency with which students use scientific conceptions and alternative conceptions show that students use alternative conceptions in learning chromosome, DNA and gene more often than they use scientific conceptions and that students were not challenged effectively in class to help them re-conceptualise the intuitive notions they brought into class (Duit & Treagust, 2013). This study has contributed to literature by establishing which of the two conceptions, scientific or alternative, occurs more often in learning chromosome, DNA and gene by senior high students, as the existing literature reports the existence of alternative conceptions alongside scientific conceptions but does not indicate the difference in the frequencies of their usage. This finding is an indication that senior high students have poor conceptual understanding of the genetics concepts studied – chromosome, DNA and gene – resulting in their using their alternative conceptions more often than the scientific conceptions.

Furthermore, on the matter of how senior high school teachers perceive genetics, though the current study did not investigate teacher difficulties and conceptions in genetics, the findings of this study have shown that teachers have only a slightly positive perception towards teaching and learning of genetics and do not perceive genetics as an abstract concept. The perception of genetics as not being abstract does not support what is in the existing literature (Knippels, 2002; Knippels et al, 2005; Altunoølu & Seker, 2015) which thus calls for further investigation to find out whether teachers in the field currently have found a way of teaching genetics to the understanding of students. The current study's finding that senior high school teachers emphasize the use of student-student and student-teacher interactions is a misnomer. This is because such interactions are known to help students restructure their ideas appropriately if used well (Saloum & BouJaoude, 2017). However, students use their alternative conceptions more frequently than they do the scientific conceptions indicating that teachers may not be using the student-student and student-teacher interactions effectively enough.

Additionally, the current study's finding that teachers use a variety of methods and strategies in their genetics lessons is laudable. This is because if teachers vary their methods and strategies as the need may be in a bid to address students' needs during lessons, it ensures the acquisition of scientific conceptions by students. However, teachers were inconsistent in the teaching methods and strategies they claim to use, and what they actually use when further probed.

Finally, the finding on the effectiveness of the O-D-R conceptual change approach shows the approach is effective. This is because it helps in overcoming students alternative conceptions leading to the development of scientific conception. Thus, it can be recommended for biology educators and teachers alike to use it in their genetics lessons to ensure effective development of scientific concepts on the part of students. The O-D-R conceptual change approach is also effective in meeting students' expectations in learning genetics.

Recommendations

Based on the findings of this study, the following recommendations are made for educational policy and practice:

1. As students exhibit alternative conceptions in chromosome, DNA and gene, and frequently use alternative conceptions in learning genetics, teacher educators should prepare pre-service senior high school biology teachers to adopt conceptual change approaches that can help challenge these alternative conceptions.
2. The Ministry of Education, through Ghana Education Service, should organise short courses for in-service senior high school biology teachers to help them with the content matter in genetics. Also, senior high schools should be equipped with the necessary teaching and learning resources to enable teachers teach genetics more effectively.
3. Curriculum developers must find more effective ways of presenting the subject matter in genetics to senior high school students taking into account students' misperceptions and difficulties.
4. Since the O-D-R Conceptual Change Approach was effective in helping students develop scientific conceptions, the Ministry of Education through the Ghana Education Service should organize in-service training for senior high school biology teachers to use the O-D-R conceptual change approach in teaching genetics.

Suggestions for Further Research

1. The study explored students' alternative conceptions and other conceptual difficulties in chromosome, DNA and gene in senior high schools. The study however, did not consider teacher alternative

conceptions and other conceptual difficulties in the three genetics concepts. It is, therefore, recommended that a future research be conducted to look into teacher alternative conceptions and other conceptual difficulties in genetics as well.

2. The study examined the effectiveness of O-D-R conceptual change approach in helping students develop scientific conceptions in chromosome, DNA and gene. However, further research should focus on experimental designs in order to make statistical generalisations on the effectiveness of the O-D-R conceptual change approach in helping students to overcome their difficulties in other biology concepts in senior high school.
3. The current study examined students' conceptions in chromosome, DNA and gene, but did not examine students' conceptions vis a vis teachers conceptions of the three concepts. It is thus recommended that a future study be conducted to concurrently examine students and teachers' conceptions.

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APPENDICES

APPENDIX A

Teachers' Questionnaire on their Teaching Practices, Challenges and Nature of Genetics, TQTPCNG

You are humbly invited to participate in a research study aimed at improving students' conceptions in genetics, by responding to the following questions as best as you can. All information that is collected in this study will be treated confidentially.

This questionnaire is addressed to biology teachers, who are asked to supply information about their academic and professional backgrounds, instructional practices, and attitudes towards teaching biology, specifically genetics. Since you have been selected as part of the sample, your responses are very important in helping to describe genetics lessons at the senior high level.

Some of the questions in this questionnaire ask about **your genetics class(es)**. It is important that you answer each question carefully so that the information provided reflects your situation as accurately as possible. It is estimated that it will require approximately 25 minutes to complete this questionnaire. There are no "right" or "wrong" answers to any of these items. The questionnaire is designed to provide information about teachers' professional experiences, opinions, and classroom activities with respect to the teaching of genetics.

Your cooperation in completing this questionnaire is greatly appreciated.

Section A: Biodata

1. Age

Under 25 ……………………………………………………………….... [ ]

25 – 29 ……………………………………………………………………. [ ]

30 – 39 …………………………………………………………………….. [ ]

40 – 49 ……………………………………………………………………. [ ]

50 – 59 ……………………………………………………………………. [ ]

60 or more ……………………………………………………………….. [ ]

2. Sex: female [ ] male [ ]

3. By the end of this school year, how many years would you have been teaching biology at the SHS) ……………………………..

4. How many periods do you teach Biology each week in the school? ………………………….

5. What is your highest academic/professional qualification?

Dip. Ed [ ] B. Ed [ ] B. Sc [ ] M. Ed [ ] M. Phil [ ] Ph.D.[ ]

6. Are you a professional teacher? (Please tick the appropriate box)

Yes [ ] No [ ]

7. At which level of education did you last study biology?

Basic School [ ] SHS [ ] Diploma [ ] First Degree [ ] Second Degree [ ] Third Degree [ ]

8. What is your teaching load in the school? ……………………………

SECTION B: Challenging topics for teachers and students

9. Tick the genetics topic(s) you find difficult teaching in senior high school:

Basic terms used in genetics	[ ]
Structure of Chromosomes	[ ]
Inheritance	[ ]
Mendel's first and second laws of inheritance	[ ]
Mononhybrid inheritance	[ ]
Dihybrid inheritance	[ ]
Linkage	[ ]
Sex determination	[ ]
Sex linked characters	[ ]
Gene interactions	[ ]
Heridity	[ ]
Variation	

10. Tick the genetics topic(s) your students find difficult learning in senior high school:

Basic terms used in genetics	[ ]
Structure of Chromosomes	[ ]

Inheritance [ ]
Mendel's first and second laws of inheritance [ ]
Mononhybrid inheritance [ ]
Dihybrid inheritance [ ]
Linkage [ ]
Sex determination [ ]
Sex linked characters [ ]
Gene interactions [ ]
Heridity [ ]
Variation [ ]

SECTION C: Characteristics for succeeding in genetics study

To be good in genetics, how important do you think it is for students to:

	Not Important	Somewhat Important	Important	Very Important
11) remember formulas and procedures				
12) think in a sequential and procedural manner				
13) understand genetics concepts, principles, and strategies				
14) be able to think creatively				
15) be able to supply reasons for their conclusions				

SECTION D: Nature of genetics

To what extent do you agree or disagree with each of the following statements?

Statement	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
16) Genetics is an abstract subject					
17) Genetics is a formal way of representing the real world					
18) Genetics is a practical and structured guide for addressing real situations					

SECTION E: Attitudes that promote success in genetics study

To what extent do you agree or disagree with each of the following statements?

Statement	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
19) Some students have a natural talent for genetics while others do not					
20) It is important for teachers to give students prescriptive and sequential directions for learning genetics					
21) Focusing on rules is not a good idea.					
22) Focusing on rules gives students the impression that					

genetics is a set of procedures to be memorized.					
23) Students see a genetics task as the same even when they are represented in different ways (e.g. using picture, concrete material, symbol set, etc)					
24) When teachers show more friendliness towards students it promotes the teaching of genetics.					
25) When teachers understand their students, it promotes the teaching of genetics.					

SECTION F: Teaching practices for teaching genetics

In your genetics lessons, which of these areas do you emphasize most?

	Almost Never	Some Lessons	Most Lessons	Almost Every lesson
26) Work on problems for which there is no immediately obvious method of solution				
27) Write explanations about what was observed				

28) whole class interaction with the teacher				
29) students interacting with one another				

SECTION G:

State the frequency at which you perform/organize each of the following activities over a month of lessons in your genetics class:

	Rarely/Never	Often	Very Often	Almost Always	Always
30) homework review					
31) teacher-guided student practice					
32) re-teaching and clarification of content/procedures					
33) student independent practice					
34) tests and quizzes					
35) teacher demonstrations					
36) students demonstrations					

APPENDIX B

Students' Achievement Test on Genetics, SATG

You are humbly invited to participate in a research study aimed at improving senior high students' conceptions in genetics, by responding to the following questions as best as you can. All information that is collected in this study will be treated confidentially.

This diagnostic test is directed at students who have been taught genetics at the senior high school. (They should be / should have been elective biology students). Since you have been selected as part of the sample, your responses are very important in helping to describe students' conception of some concepts in genetics at the senior high level.

Some of the questions in this questionnaire require you to provide only written explanations of concepts in genetics, while others require that you choose answers from given options, as well as give explanations for the choice(s) made. It is important that you answer each question carefully so that the information provided reflects your understanding as accurately as possible. It is estimated that it will require approximately

30 minutes to complete this questionnaire.

Your cooperation in completing this diagnostic test is greatly appreciated. This is solely for research purposes. You will not be graded as part of your current schooling activities.

Please answer the following questions to the best of your ability.

SECTION A:

Age: **Current Class/Level:** **Sex:** Male [ ] Female [ ]

SECTION B:

Tick the genetics topic(s) you find (found) difficult learning in senior high school:

Basic terms used in genetics [ ]
Structure of Chromosomes [ ]
Inheritance [ ]
Mendel's first and second laws of inheritance [ ]
Monohybrid inheritance [ ]
Dihybrid inheritance [ ]
Linkage [ ]
Sex determination [ ]
Sex linked characters [ ]
Gene interactions [ ]
Heredity [ ]
Variation [ ]

SECTION C:

1) What do you understand by the term 'gene'?

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2) Differentiate between a chromosome and a DNA molecule in terms of size.

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3) How many genes can one DNA molecule contain? Explain your answer.

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4) Can one gene contain many chromosomes? Explain your answer.

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5) Explain the relationship between DNA and a chromosome (use drawings if you find them helpful!).

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6) Explain the relationship between DNA and a gene (use drawings if you find them helpful).

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7) In a single cell, would there be more of chromosomes or genes? Explain your answer.

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8) Is the DNA in a single skin cell different from the DNA in a single muscle cell? Explain your answer.

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9) What is an allele?

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10) Does a muscle cell have only the genes needed to function as part of a muscle? Explain your answer.

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11) Does a skin cell have a gene for eye color? Explain your answer.

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12) Can there be different versions (forms) of a single gene?

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13) Explain why two siblings (same parents) will look different from each other.

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14) Explain the relationship between a gene and a protein (use drawings if you find them helpful!).

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APPENDIX C

Interview Guide for Teachers on Effective Teaching Practices for Genetics, IGTETPG

1. For how many years have you been teaching Biology at the Senior High School?

2. How many hours per week do you normally spend on your teaching activities altogether including times spent in and out of school preparing for lesson?

3. How important do you think it is for students to understand how genetics is used in the real world?

4. Do you find some genetics concepts challenging to teach?

5. What do you think makes this topic challenging for you?

6. How have you been coping or dealing with the challenges over the years?

7. Which genetics topic(s) do your students find challenging?

8. How have you been addressing these challenges to improve students' understanding of the concepts?

9. What instructional materials do you usually use in teaching genetics?

10. How do you ensure that students participate fully in your genetics lesson?

APPENDIX D

PRETEST ACHIEVEMENT TEST, PreSATG

Students' Achievement Test on Genetics, SATG

You are humbly invited to participate in a research study aimed at improving senior high students' conceptions in genetics, by responding to the following questions as best as you can. All information that is collected in this study will be treated confidentially.

This diagnostic test is directed at students who have been taught genetics at the senior high school. (They should be / should have been elective biology students). Since you have been selected as part of the sample, your responses are very important in helping to describe students' conception of some concepts in genetics at the senior high level.

Some of the questions in this questionnaire require you to provide only written explanations of concepts in genetics, while others require that you choose answers from given options, as well as give explanations for the choice(s) made. It is important that you answer each question carefully so that the information provided reflects your understanding as accurately as possible. It is estimated that it will require approximately

30 minutes to complete this questionnaire.

Your cooperation in completing this diagnostic test is greatly appreciated. This is solely for research purposes. You will not be graded as part of your current schooling activities.

Please answer the following questions to the best of your ability.

SECTION A:

Age: **Current Class/Level:** **Sex:** Male [ ] Female [ ]

SECTION B:

Tick the genetics topic(s) you find (found) difficult learning in senior high school:

Basic terms used in genetics [ ]
Structure of Chromosomes [ ]
Inheritance [ ]
Mendel's first and second laws of inheritance [ ]
Monohybrid inheritance [ ]
Dihybrid inheritance [ ]
Linkage [ ]
Sex determination [ ]
Sex linked characters [ ]
Gene interactions [ ]
Heredity [ ]

Variation [ ]

SECTION C:

1) Explain the relationship between a gene and a protein (use drawings if you find them helpful!).

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2) Explain why two siblings (same parents) will look different from each other.

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3) Can there be different versions (forms) of a single gene?

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4) Does a skin cell have a gene for eye color? Explain your answer.

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5) Does a muscle cell have only the genes needed to function as part of a muscle? Explain your answer.

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6) What is an allele?

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7) Is the DNA in a single skin cell different from the DNA in a single muscle cell? Explain your answer.

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8) In a single cell, would there be more of chromosomes or genes? Explain your answer.

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9) Explain the relationship between DNA and a gene (use drawings if you find them helpful).

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11) Can one gene contain many chromosomes? Explain your answer.

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12) How many genes can one DNA molecule contain? Explain your answer.

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13) Differentiate between a chromosome and a DNA molecule in terms of size.

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14) What do you understand by the term ‘gene’?

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APPENDIX E

POSTTEST ACHIEVEMENT TEST, PostSATG

Students' Achievement Test on Genetics, SATG

You are humbly invited to participate in a research study aimed at improving senior high students' conceptions in genetics, by responding to the following questions as best as you can. All information that is collected in this study will be treated confidentially.

This diagnostic test is directed at students who have been taught genetics at the senior high school. (They should be / should have been elective biology students). Since you have been selected as part of the sample, your responses are very important in helping to describe students' conception of some concepts in genetics at the senior high level.

Some of the questions in this questionnaire require you to provide only written explanations of concepts in genetics, while others require that you choose answers from given options, as well as give explanations for the choice(s) made. It is important that you answer each question carefully so that the information provided reflects your understanding as accurately as possible. It is estimated that it will require approximately

30 minutes to complete this questionnaire.

Your cooperation in completing this diagnostic test is greatly appreciated. This is solely for research purposes. You will not be graded as part of your current schooling activities.

Please answer the following questions to the best of your ability.

SECTION A:

Age: **Current Class/Level:** **Sex:** Male [ ] Female [ ]

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Gene interactions [ ]
Heredity [ ]

Variation [ ]

SECTION C:

1) What do you understand by the term 'gene'?

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2) Differentiate between a chromosome and a DNA molecule in terms of size.

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3) How many genes can one DNA molecule contain? Explain your answer.

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5) Explain the relationship between DNA and a chromosome (use drawings if you find them helpful!).

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APPENDIX F

O-D-R GENETICS LESSONS

Lesson 1: The Chromosome Concept

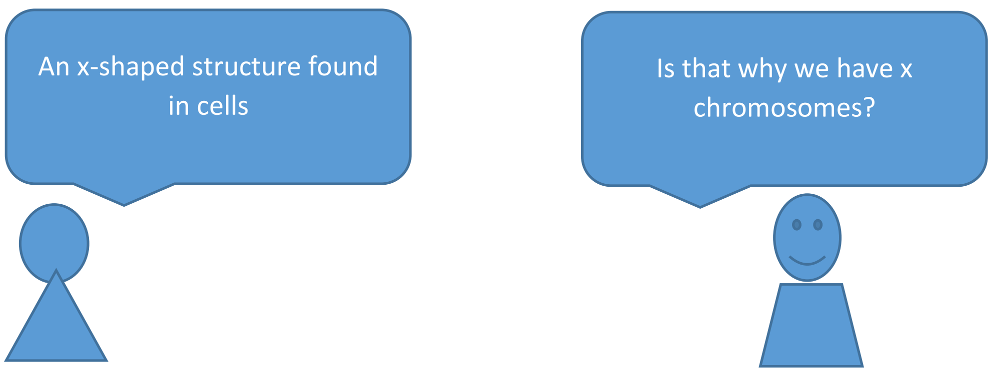
The aim of lesson 1 was to first elicit students' prior (alternative) conceptions with regards to chromosome concept. Then the students are taken through activities that help them conceptualize the chromosome concept appropriately.

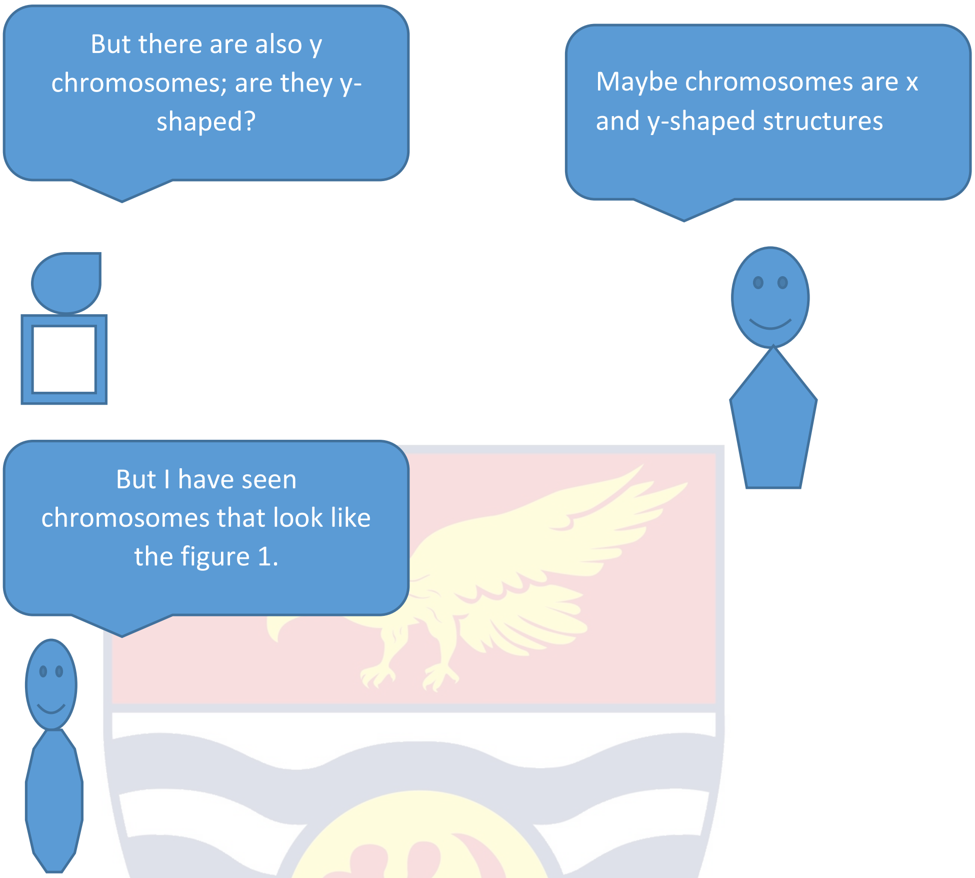
Orientation phase

Concept cartoons depicting a number of alternative conceptions on chromosome are projected. Students are instructed to indicate which of the ideas on the cartoons they agree with. Students then pair up and explain the reasons for their choices. They are told to register their agreement or otherwise with their group members. After 10 minutes, each group shares their agreements/disagreements with the entire class. The whole activity is slated for 25 minutes.

Concept cartoon on chromosome:

What comes to your mind when you hear the word chromosome? The cartoons that follow are students who expressed their views. Indicate which of the ideas you agree or disagree with. Give reasons for your choices and discuss with your group members. Please share your views with the whole class after 10 minutes of discussion in your group





Discovery phase:

Teacher shares some basic information about chromosome, such as what it is made of. Students are then taken through activities that enable them visualize how the chromosome is formed. The condensation activity was used. Before the activity students are encouraged to feel free to ask questions or share their ideas. ‘Condensation’ activity: If you have a very long thread that you have to put into a tiny space what will you do? You have been provided with a length of thread and 5 lime fruits. In your groups, measure the length of the thread. Then tie the thread around the lime at equal intervals. Now, measure the length of the thread tied around the lime fruits from one end to the other. Compare the lengths before and after the tying. What else do you notice about the thread before and after tying it around the lime fruits? (This activity lasts for 15 minutes).

Restructuring phase:

Students are given questions to answer before video show.

Videos depicting the condensation of DNA into chromatin, and of chromatin into chromosome are shown to students.

Questions given prior to the video show are re-distributed and students are asked to answer them on pieces of paper given.

Questions:

1. Describe the appearance of DNA before being ‘changed’ into chromatin.

2. What was involved in ‘changing’ DNA into chromatin?

3. How was the chromatin ‘converted’ into chromosome?

4. So what will you say is the composition of chromosome? Explain.

Students are then shown the initial concept cartoon and asked to re-engage with the ideas in it through discussion at their group levels, and finally at the class level.

Lesson 2: The DNA Concept

The aim of lesson 2 is to first elicit students’ prior (alternative) conceptions with regards to the DNA concept. Then the students are taken through activities that help them conceptualize the DNA concept appropriately.

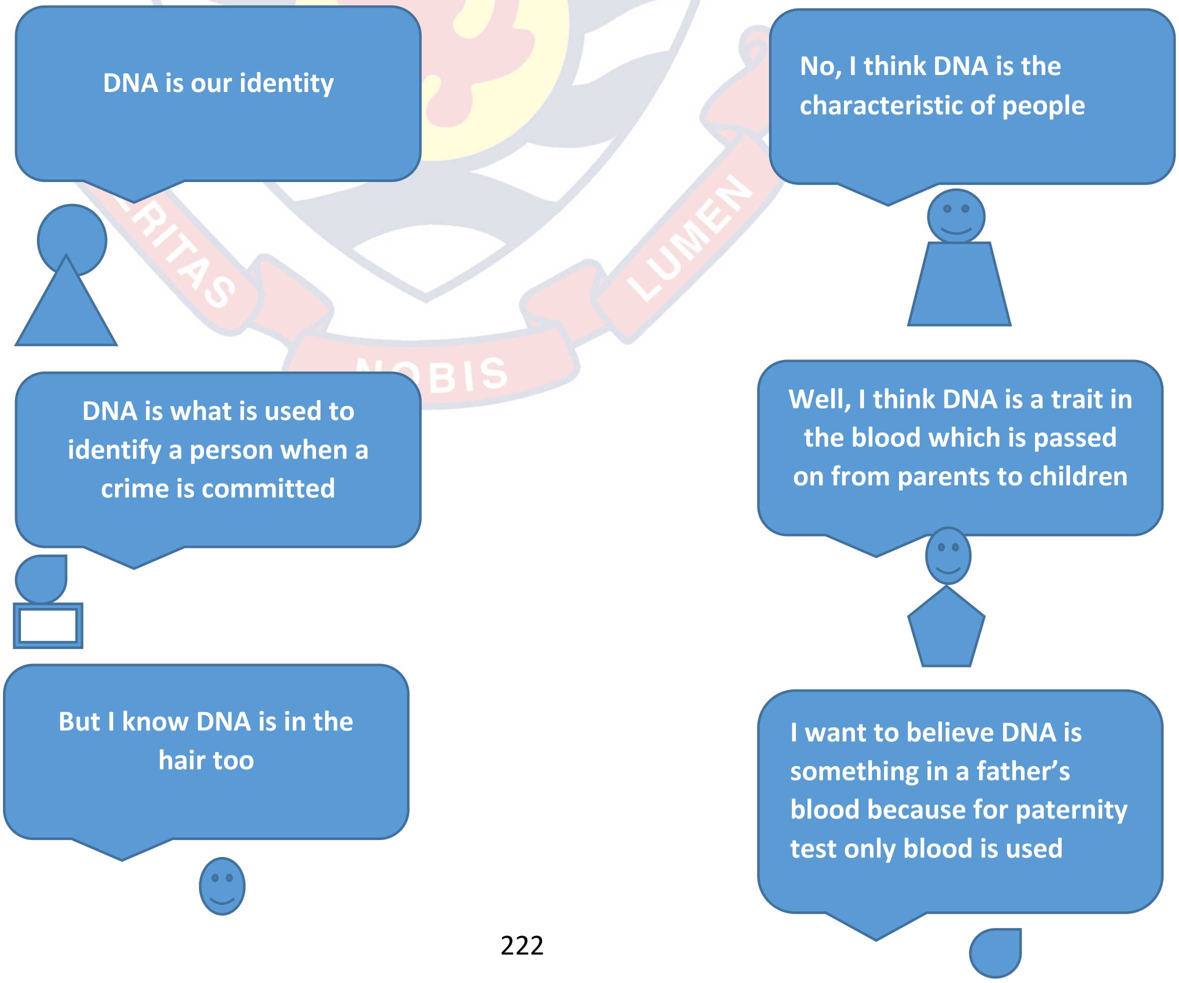
Orientation phase:

Concept cartoons depicting a number of alternative conceptions about DNA are projected. Students are asked to indicate which of the ideas on the cartoons they agree with. Students then pair up and explain the reasons for their choices. They are told to register their agreement or otherwise with their group members. After 10 minutes, each group shares their agreements and disagreements with the entire class. The whole activity is slated for 25 minutes.

Concept cartoon on DNA:

What comes to your mind when you hear 'DNA'? The cartoons that follow are students who expressed their views. Indicate which of the ideas you agree or disagree with. Give reasons for your choices and discuss with your group member. Please share your views with the whole class after 10 minutes of discussion in your group

What is DNA?



Discovery phase:

Teacher shares some basic information about DNA, such as what it is made of. Students are then taken through activities that enable them visualize the structure of the DNA. The zipper activity is used. Before the activity students are encouraged to feel free to ask questions or share their ideas. They are then asked to join their usual groups.

Zipper activity: You have been provided with 2 zippers and a magnifying glasses. Unzip the zipper and use the magnifying glass to observe the 'teeth' of the zipper on the two sides. Write down your observation about how the 'teeth' look like. Observe the cloth part of the zipper and note how the teeth are attached to the cloth. Slowly zip the zipper up, as you use the magnifying glass to observe how the two sides of the teeth close up. What helps the two rows of teeth to stick together as you zip it up? Discuss your observations in your groups. Be prepared to share your observations with the whole class.

Whole class discussion of observations from the activity is done. Teacher reminds student of information shared with them about the DNA before the activity. She then helps them relate the structure of the DNA to the zipper – cloth part on each side of the two rows of 'teeth' equated to sugar-phosphate backbone of DNA; 'teeth' equated to nitrogenous bases; one row of teeth looking like the opposite of the other row makes it possible to zip/close the zipper to form one piece, similar to the two strands of the DNA bonding together to give its characteristic double stranded structure.

Restructuring phase:

Students are given questions to answer before a video show.

Video depicting the structure of DNA is shown to students.

Questions given prior to the video show are re-distributed after video show, and students are asked to answer them on pieces of paper given.

Questions:

1. What basic units form a DNA molecule?

2. List the constituents of the basic unit of the DNA.

3. Which of the constituents in (2) form the 'backbone' of the DNA? Which forms the 'inner' part of the DNA?

4. What 'binds' the two sides of the DNA together?

5. What about the DNA molecule causes it to be helical?

Students are then shown the initial concept cartoon and asked to re-engage with the ideas in it through discussion at their group levels, and finally at the class level.

Lesson 3: The Gene Concept

The aim of lesson 3 is to first elicit students' prior (alternative) conceptions with regards to the gene concept. Then the students are taken through activities that help them conceptualize the gene concept appropriately.

Orientation phase:

Concept cartoons depicting a number of alternative conceptions about gene are projected. Students are asked to indicate which of the ideas on the cartoons they agree with. Students then pair up and explain the reasons for their choices. They are told to register their agreement or otherwise with their group members. After

10 minutes, each group shares their agreements and disagreements with the entire class. The whole activity is slated for 25 minutes.

Concept cartoon on gene:

What comes to your mind when you hear 'DNA'? The cartoons that follow are students who expressed their views. Indicate which of the ideas you agree or disagree with. Give reasons for your choices and discuss with your group member. Please share your views with the whole class after 10 minutes of discussion in your group

In living things where can we find genes?

A gene is found in the blood and is passed on to offspring that way

Genes are in the sperm only

Genes are in the ovum only

Genes are in the reproductive organs

Genes are not found in body cells, they are only in sex cells

What is a gene?

Genes are what make you look like your family

A gene is a particle found in the blood of organisms that passes traits to offspring

I think a gene is what makes you look like you

To me a gene is a trait in the blood that is transferred from parents to children

Discovery phase:

Teacher shares some basic information about gene such as what it is made of. Students are then taken through activities that enable them visualize the structure of the gene. The zipper-snipping activity is used. Before the activity students are encouraged to feel free to ask questions or share their ideas. They are then asked to join their usual groups.

The zipper-snipping activity:

You have been provided with a zipper, a pair of scissors and a measuring rule Use the ruler to measure different lengths of the zipper successively (e.g. 2 cm, 3 cm, 4 cm, 5 cm) and label each length from “a” to ‘e”. Carefully cut the zipper into the different lengths marked on it. What will you call each of the strips of zipper you have? What is each strip made of? Compare each strip to the whole zipper (taken as DNA). What will you say each of the strips is with regards to the DNA (i.e. the whole zipper)?

Restructuring phase:

Students are given questions to answer before a video show.Video depicting what a gene is, is shown to students.

Questions given prior to the video show are re-distributed after video show, and students are asked to answer them on pieces of papers given.

Questions:

1. What forms a gene?

2. How long can a gene be?

3. What is the function of a gene?

4. How does a gene relate to DNA and chromosome?

Students are then shown the initial concept cartoon and asked to re-engage with the ideas in it through discussion at their group levels, and finally at the class level.

Conclusion:

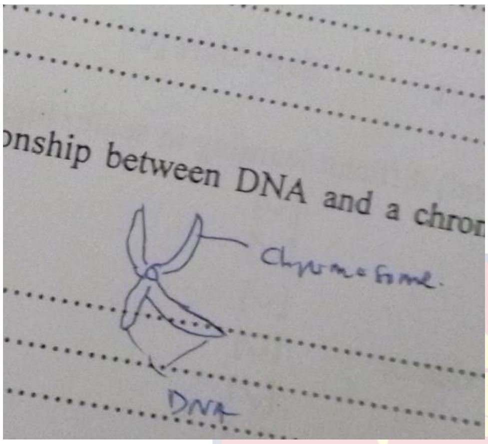
Students are helped to conceptualise the three concepts as they relate to each other using the analogy of the cassette recorder:

A cassette is a large bundle of tape containing many song tracks. It is like a Chromosome. The tape in the cassette is used to record information (i.e. songs). It is like the DNA. One song or track on the tape is like a Gene.

Different versions of the same song (such as remixes) are like Alleles

APPENDIX G

Sample Students' Responses to SATG



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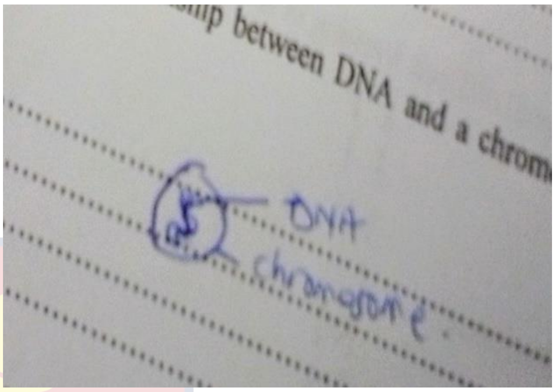

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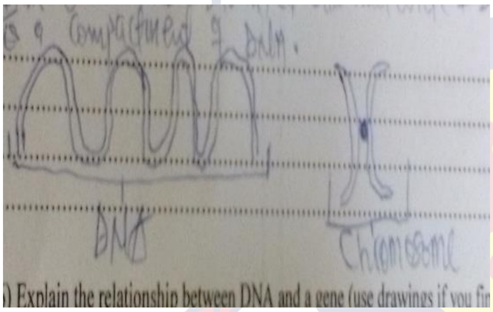

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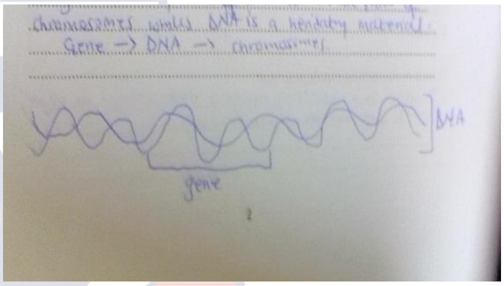

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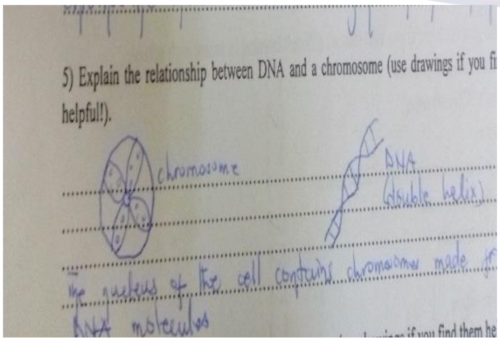

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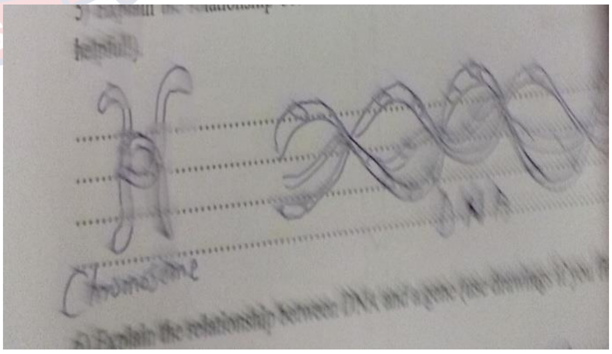

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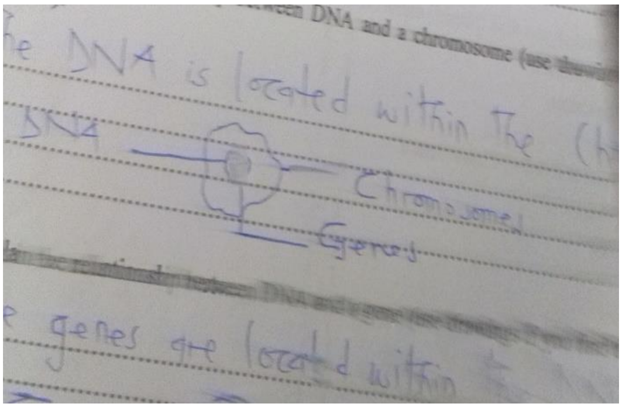

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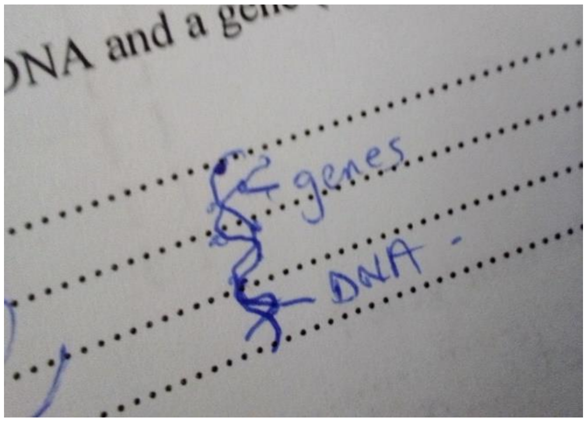

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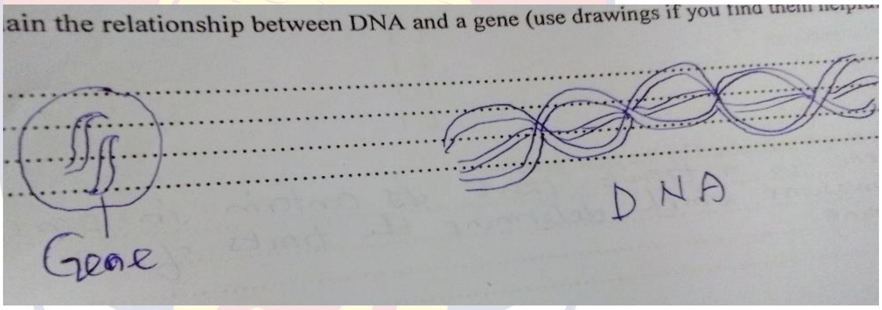

OCDR49