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Identification of Students' Misconceptions and their Causes and How these Misconceptions Influenced the Study of Genetics at Bonzo Kaku Senior High School in Ghana

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ABSTRACT
This study examined the identification of students' misconceptions and their causes and how these misconceptions influenced the academic performance in selected genetics topics at Bonzo Kaku Senior High School in Ghana's Ellembelle District. Concerns over persistent misconceptions, declining achievement, and low student motivation in genetics led to the adoption of a pragmatic action research design grounded in Kolb's Experiential Learning Theory. The research used a convergent parallel mixed-methods framework, gathering both quantitative and qualitative data from a purposively selected group of 212 third-year students. Teaching interventions incorporating PhET simulations and practical laboratory work were designed to address key genetics concepts, including gene expression, inheritance patterns, and chromosomal behavior. Academic performance was measured through pre- and post-tests, student perceptions were gathered via questionnaires, and in-depth qualitative insights were obtained through interviews. Quantitative analysis employed the Wilcoxon rank test, Mann-Whitney U test, Two-Way ANOVA, and descriptive statistics, while qualitative data were interpreted through thematic analysis. Findings revealed that students harboured considerable misconceptions about genetics: of the 20 multiple-choice questions administered, only three were answered correctly without any misconceptions. The study also identified the highly abstract nature of genetics instruction as a key driver of these misunderstandings, underscoring the need for the PhET and laboratory-based interventions that followed. The instructional intervention yielded substantial gains in both genetics' performance and laboratory competencies, with scores rising by 46% and 50%, respectively. Notably, female students outperformed their male counterparts by 12% in genetics and by 10% in laboratory skills following the intervention. The study further found that PhET simulations had a more pronounced positive effect on the genetics performance of female students compared to males, though no gender-based differences emerged in the development of laboratory skills. Beyond measurable academic outcomes, the intervention cultivated greater student engagement, stronger critical thinking abilities, and a heightened interest in science. The study concludes that combining PhET simulations with hands-on laboratory activities represents a highly effective instructional strategy for teaching abstract and complex scientific content. It advocates for curriculum reform, targeted professional development for educators, and broader access to both digital tools and laboratory facilities. In doing so, the study makes a meaningful contribution to the advancement of STEM education in Ghana through an evidence-based, student-centered approach that promotes both academic excellence and scientific literacy.

Keywords: Biology, Genetics, Genes, Heredity, Genetic variation, PhET Simulation, Biology Laboratory Experiment, Academic performance, Conceptual understanding in genetics

INTRODUCTION

Genetics, a major branch of biology, focuses on the study of genes, heredity, and variations among living organisms. The subject encompasses complex concepts that frequently require practical activities and visual representations to facilitate effective understanding. Genetics enables learners to understand the functioning, inheritance, and evolution of living organisms (Nurse & Hayles, 2019), making it an essential component of biology education. According to Correia et al. (2019), genetics education is fundamental in developing students' understanding of key biological principles.

Despite its significance, genetics remains one of the biology topics that commonly leads to misconceptions among students (Osman et al., 2017; Stern & Kampourakis, 2017). Studies have further shown that students in many countries perceive genetics as difficult to learn (Fauzi et al., 2021). This difficulty is largely attributed to the presence of numerous unfamiliar terminologies and the abstract nature of genetic concepts. Bolognesi and Vernillo (2019) explained that concepts become abstract when learners lack clear mental representations or references to support understanding. Furthermore, the teaching of genetics is often dominated by teacher-centred approaches, characterised by lectures, extensive teacher explanations, limited student discussions, and inadequate integration of technology to support instruction and learning (Casanoves et al., 2017).

Before formally studying biology in high school, students often come with prior knowledge about biology. However, these initial concepts are sometimes incorrect or conflict with expert accepted scientific ideas. These misunderstandings, often called misconceptions or alternative concepts, stem from experiences and observations in elementary school or everyday life (Clark & Chamberlain, 2014). Misconceptions, also known as preconceived ideas, naive theories, or non-scientific beliefs, are interpretations that students hold which have not been scientifically validated (Kiliç & Sağlam, 2014; Nowgen, 2012).

Research by Vlčková, Kubiatko, and Usak (2016) shows that misconceptions arise when students lack proper tools or media to visualize complex concepts. Some scholars suggest that misconceptions are a byproduct of how students form knowledge. In today's genomic era, where genetics influences health, agriculture, and technology, it is crucial for students to understand genetic concepts rather than view genetic information as a "black box" (Nowgen, 2012). Many national education systems have therefore incorporated genetics into their curricula, including at the lower secondary school level (Kiliç & Sağlam, 2014; Aldahmash & Alshaya, 2012).

Haskel-Ittah and Yarden (2018) further identified persistent misconceptions about genetic material among high school students, underscoring the complexity and perceived difficulty of learning genetics. According to Kiliç and Sağlam (2014), students find genetics challenging because the concepts are abstract and disconnected from daily life, leading to misunderstandings. Since the 1980s, researchers have explored how well schools prepare students for understanding genetics. Studies show that students often confuse basic terms like gene, chromosome, and allele and struggle with concepts like gene expression and cellular functions (Clark & Chamberlain, 2014; Aldahmash & Alshaya, 2012; Lewis & Wood-Robinson, 1998). Unfortunately, recent findings suggest that these issues persist (Haskel-Ittah & Yarden, 2018; Vlčková, Kubiatko, & Usak, 2016). A key factor contributing to these enduring misconceptions is that research frequently emphasizes students' conceptual errors without adequately examining their underlying causes.

Research indicates that misconceptions may be influenced by national curricula (Osman, BouJaoude, & Hamdan, 2017), textbooks, teaching methods (Weston & Laursen, 2015; Adebayo & Oladele, 2016), and even media (Agboghoroma & Oyovwi, 2015). Learning and academic performance can also be impacted by various factors, such as the school environment, teacher qualifications, student abilities, and sociocultural contexts, including misconceptions and socioeconomic status. Science is often seen as difficult, regardless of one's background, and genetics is considered particularly complex. Genetics deals with heredity and the transmission of traits from parents to offspring. However, the mechanisms of gene transmission and variation are intricate and abstract, making them hard for students to grasp without special tools or instruments (Weston & Laursen, 2015; Adebayo & Oladele, 2016). Furthermore, terms like gene, DNA, and chromosomes are often used interchangeably, adding to students' confusion (Agboghoroma & Oyovwi, 2015). Though students may have some understanding of how traits are inherited, their understanding often doesn't align with scientific principles, especially regarding the microscopic mechanisms involved in genetic variation.

Misconceptions are not confined to a single educational stage but occur across the entire learning continuum, from primary education through to tertiary level, and they are also evident among teachers. Mustami (2016) argues that these misconceptions frequently stem from the use of inappropriate instructional approaches and ineffective teaching media that do not adequately represent abstract scientific concepts. In addition, the way learners construct knowledge cognitively may itself contribute to the formation of alternative conceptions. Supporting this view, Osman, BouJaoude, and Hamdan (2017) reported that preservice teachers demonstrate misconceptions in areas such as global warming, the greenhouse effect, and ozone layer depletion, largely shaped by their pre-existing scientific beliefs. Mustami (2016) further observed that some biology textbooks also contain conceptual inaccuracies, which are subsequently transferred to both teachers and students who rely on them. Once formed, these misconceptions tend to be robust, resistant to change, and often persist even after formal instruction.

From a conceptual perspective, Toth, Ludvico, and Morrow (2014) describe misconceptions as components of a broader, interconnected knowledge framework through which learners interpret their experiences. These alternative conceptions often develop early, sometimes prior to formal schooling. Within biology education, genetics remains particularly challenging, with persistent misconceptions widely documented (Mustami, 2016). Empirical studies have highlighted significant difficulties among primary and secondary students in understanding cell biology and genetics (Al Musawi et al., 2017; Yuliati, Riantoni, & Mufti, 2018), although focused investigations into cell biology misconceptions remain relatively limited. Benzer and Ünal (2021) specifically identified cell division as a concept that students struggle with, despite its foundational importance in genetics, reproduction, and development. Core biological concepts such as genes, DNA, chromosomes, and cell division are consistently reported as difficult by both learners and teachers (Astutik & Prahani, 2018).

Even after instruction, research shows that students often retain pre-existing misconceptions that conflict with accepted scientific explanations (Benakli et al., 2017). Arabacioglu and Unver (2016) attribute these difficulties to learners' inability to clearly differentiate between processes such as replication, synapsis, and disjunction, as well as confusion regarding whether these occur in mitosis, meiosis, or both. Additional challenges include misunderstanding the distinction between chromatids and chromosomes, and between replicated and non-replicated chromosomes. These conceptual difficulties significantly hinder learners' understanding of cell division, which is essential for comprehending growth, development, and inheritance (Astutik & Prahani, 2018). Further studies in genetics problem-solving indicate that students often struggle with meiosis, and that accurate understanding of genetics is heavily dependent on a solid grasp of cell division processes. Benakli et al. (2017) also found that learners frequently lack understanding of chromosome behaviour and genetic material transfer during cell division, which further impedes their grasp of genetics. Toth, Ludvico, and Morrow (2014) additionally revealed that even prospective science teachers hold misconceptions about genes and chromosomes, as evidenced in their written explanations and diagrams.

Objective of the study

The main objective of this study is to examine and assess the effects of incorporating Physics Education Technology (PhET) simulations alongside hands-on laboratory experiments in the teaching and learning of genetics concepts at Bonzo Kaku Senior High School in the Ellembelle District of the Western Region. Specifically, the study aims to;

1. identify students' misconceptions and conceptions in genetics.
2. examine the causes of students' misconceptions that lead to their poor performance in genetics.

Related literature

Theoretical Framework

The theoretical foundation of this study was Kolb's Experiential Learning Model (Kolb, 1984). Developed by David Kolb, this model conceptualises learning as a cyclical process comprising four stages: concrete experience, reflective observation, abstract conceptualisation, and active experimentation. It posits that effective learning occurs through continuous engagement in this cycle, where individuals actively experience, reflect on, conceptualise, and apply knowledge.

Kolb's model is widely regarded as an influential framework that emphasises the centrality of experience in the learning process. It is particularly relevant to laboratory-based instruction, where hands-on activities play a critical role in knowledge acquisition and skill development. The experiential learning cycle is illustrated in Figure 1):

1. **Concrete Experience**: This stage involves encountering a new experience or situation, which could be a novel encounter or a reinterpretation of existing experiences. Here, students engage in laboratory experiments where they observe genetic traits in organisms or use PhET simulations to explore genetic inheritance patterns.
2. **Reflective Observation**: Learners reflect on the new experience, focusing on any inconsistencies between their understanding and the experience itself. Students make reflective observation which involve students discussing their observations, identifying patterns, and relating them to genetic principles learned in class.
3. **Abstract Conceptualization**: Reflection leads to the development of new ideas or modifications to existing abstract concepts based on the learning experience. Students begin to understand the underlying principles and theories behind the concrete experiences. Abstract conceptualisation involves students formulating hypotheses, constructing genetic models, and applying theoretical frameworks to explain observed phenomena.
4. **Active Experimentation**: Newly formed or modified concepts are put into practice through experimentation, where learners apply their ideas in real-world scenarios to observe outcomes. Learners engage in active experimentation to test their hypotheses, validate theories, and further enhance their understanding. In genetics, active experimentation entails planning and carrying out experiments, interpreting data, and forming conclusions from the findings. According to Kolb's

learning theory, this process aligns with four distinct learning styles derived from the four-stage learning cycle:

- **Diverging (CE/RO)**: Individuals who prefer this style are imaginative, emotional, and excel at viewing situations from multiple perspectives.
- **Assimilating (AC/RO)**: Learners with this style focus on abstract concepts and reflective observation, emphasising understanding and creating theoretical models.
- **Converging (AC/AE)**: Students with this style are practical and prefer applying concepts in real-world situations through active experimentation.
- **Accommodating (CE/AE)**: This learning style emphasises concrete experience and active experimentation, where individuals learn best by doing and engaging in hands-on activities.

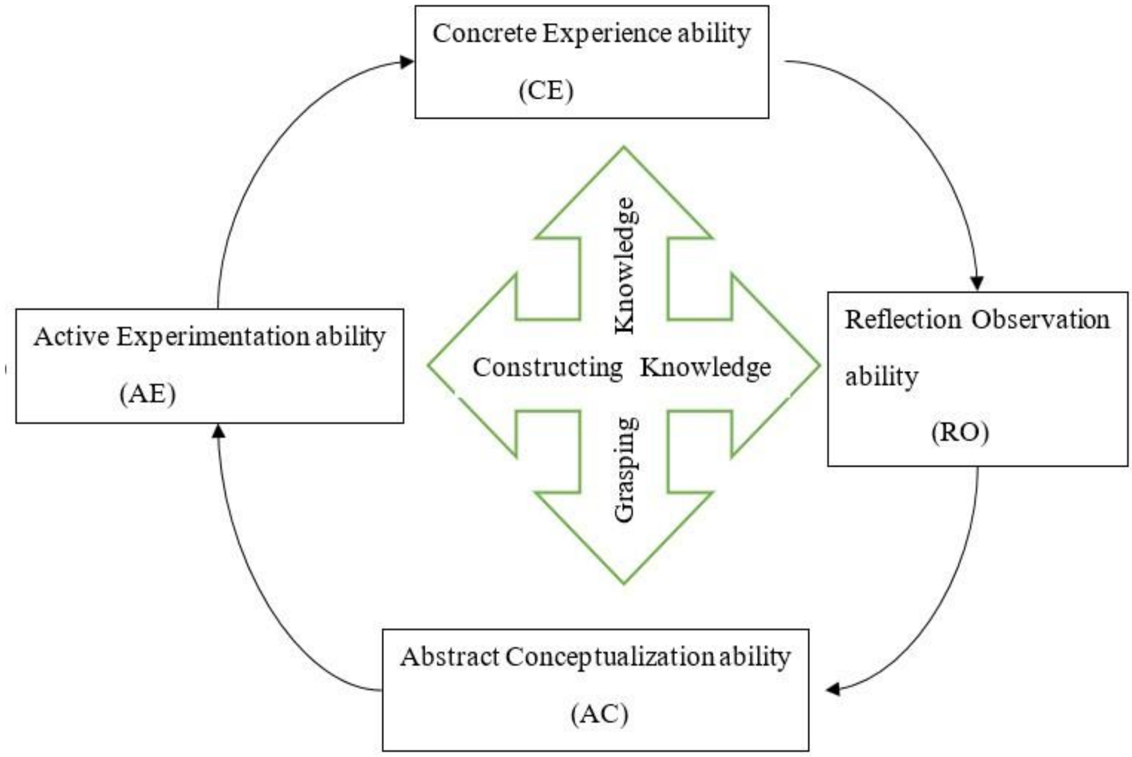

Figure 1: Kolb's experiential learning model (Adopted from Kolb, 1984)

Understanding learners' preferred learning styles is important because it enables teachers to adapt instructional strategies to meet individual needs and improve the learning experience. Kolb's model emphasizes the interconnected nature of learning, highlighting that effective learning takes place when learners move through all four stages of the cycle.

Kolb's Experiential Learning Model provides a strong framework for examining the impact of PhET simulations and laboratory experiments in genetics education. The four stages of the model, which are concrete experience, reflective observation, abstract conceptualisation, and active experimentation, closely align with both virtual simulations and practical laboratory activities. PhET simulations support students in visualising abstract genetic concepts, while laboratory experiments reinforce theoretical knowledge through direct hands-on engagement. When combined, these approaches enhance conceptual understanding, promote critical thinking, build practical skills, and improve the ability to apply genetics knowledge in real-life situations.

Through the integration of laboratory activities and interactive simulations, students can engage in direct experiences, reflect on their observations, develop conceptual understanding, and test genetic principles in practice. This approach is consistent with Kolb's theory and provides a holistic learning experience that accommodates different learning styles and strengthens students' understanding and performance in genetics.

Kolb's Experiential Learning Model also draws attention to individual differences among learners and the importance of experience and reflection in learning. In laboratory-based science instruction, especially in genetics education supported by PhET simulations, the model helps create engaging learning environments that encourage critical thinking, problem-solving skills, and deeper comprehension of complex scientific ideas.

Prior to formal biology instruction in high school, students often develop initial understandings of biological concepts. These early ideas are frequently inaccurate or inconsistent with scientifically accepted explanations. Such alternative understandings are commonly referred to as misconceptions or alternative conceptions. They are typically formed during elementary education through everyday experiences, observations, and interactions within the community (Clark & Chamberlain, 2014). Misconceptions are also described using terms such as preconceived ideas, naïve theories, non-scientific beliefs, or alternative conceptions, and they refer to interpretations that differ from scientifically validated knowledge (Kiliç & Sağlam, 2014; Nowgen, 2012).

Research by Vlčková, Kubiatko, and Usak (2016) indicates that misconceptions among students in different countries are often linked to inadequate instructional approaches and the use of teaching media that fail to clearly represent abstract scientific concepts. In addition, misconceptions may also arise from the ways in which knowledge is constructed and organised in learners' cognitive structures.

In the present genomic era, many scientific developments are grounded in molecular genetics, and the concept of genes has become widely used in media and everyday discourse. Genetics now plays a significant role in areas such as healthcare, agriculture, and biotechnology, while also raising important ethical concerns. For this reason, it is essential that students do not perceive genetic information as a "black box," but instead develop a solid understanding of fundamental genetic principles that will enable them to make informed decisions in real-life situations (Nowgen, 2012). As a result, genetics has been incorporated into many national curricula worldwide, including at the lower secondary level (Kiliç & Sağlam, 2014; Aldahmash & Alshaya, 2012).

Haskel-Ittah and Yarden (2018) identified various misconceptions held by high school students regarding genetic material through an essay-based investigation. Genetics is widely recognised as one of the more challenging areas of biology. According to Kiliç and Sağlam (2014), this difficulty arises because genetic concepts are highly abstract and not easily connected to everyday experiences. Consequently, students often perceive genetics as difficult and tedious, struggle to form a coherent understanding of the subject, and fail to establish meaningful connections among key concepts, all of which contribute to the persistence of misconceptions.

Since the 1980s, researchers have increasingly investigated whether genetics education adequately prepares students for future learning in the field. Findings from numerous studies indicate that learners commonly hold a wide range of misconceptions about genetics and often lack a deep conceptual understanding of the topic (Clark & Chamberlain, 2014). Frequently reported difficulties include confusion of fundamental terms such as gene, chromosome, allele, meiosis, and mitosis, as well as superficial understanding of these concepts. In addition, misconceptions related to gene expression, particularly how DNA influences cellular functions, have also been widely documented (Aldahmash & Alshaya, 2012; Lewis & Wood-Robinson, 1998; Saka et al., 2006).

Despite long-standing attention to these issues, recent research suggests that the situation has not improved significantly, with persistent misconceptions still being reported among students (Haskel-Ittah & Yarden, 2018; Kiliç & Sağlam, 2014; Vlčková, Kubiatko, & Usak, 2016).

One of the main reasons could be that studies often focused more on the flaws in understanding of genetic concepts than an investigation of their origin. Many studies already suggested that students' misconceptions can be influenced by the national curriculum (Osman, BouJaoude, & Hamdan 2017; Toth, Ludvico, & Morrow, 2014), textbooks and teaching methods (Weston & Laursen 2015; Adebayo & Oladele, 2016) or even the media (Agboghoroma & Oyovwi, 2015).

Learning and students' performance in educational settings can be affected by diverse factors. These could be as a result of the following - school environment (physical structure, instructional media, auxiliary spaces, etc), teachers (qualification, teaching experience, teaching style, attitude, sympathy, language skill), students (i.e. their ability, intelligence quotient, learning styles, attitude, need, and motivational styles, epistemological beliefs, etc.), as well as assessment methods, and sociocultural factors (misconceptions, socio-economic status of parents/guardians). Learners' misconceptions may develop before they enter formal schooling or arise at any stage of formal education. These misunderstandings are often described as naïve beliefs, erroneous ideas, preconceptions, or persistent conceptual difficulties. Before receiving formal instruction, students commonly hold preliminary ideas about biology that do not align with scientifically accepted explanations. Such early conceptions are usually shaped by everyday experiences and interactions within their immediate environment and are carried into formal education from the primary level onward.

Science is frequently regarded as a difficult subject to comprehend. Regardless of age, cultural background, or educational experience, individuals tend to form personal interpretations of scientific ideas, which may or may not align with accepted scientific views.

Among the various branches of biology, genetics is considered particularly challenging due to its abstract and complex nature. It deals with heredity and the transmission of genetic information from parents to offspring. Offspring inherit genes that determine characteristics such as physical traits, inherited abilities, and genetic conditions. However, understanding these processes is often difficult because the concepts are abstract and cannot be easily observed without specialised tools or representations (Weston & Laursen, 2015; Adebayo & Oladele, 2016). Furthermore, learners frequently confuse or interchange essential terms such as gene, DNA, and chromosome when explaining inheritance, which contributes to further conceptual misunderstanding (Agboghoroma & Oyovwi, 2015).

Mendelian Inheritance refers to the process of transmitting traits from one generation to another. The inherited traits are determined by genes that are passed from parents to offspring. An offspring inherits two sets of gene, one from each parent. A trait may not be observable, but its gene can be passed to the next generation. Students have an understanding on how genes play a role in transmitting traits, but this understanding is not aligned with the biological theory. Genes are passed down from parent as a whole and identically defines traits. Although this may be true based on observations, microscopically the mechanisms of genes and variations are more complex.

Misconception is also affected by all levels of learners, starting from the primary school to the university learners. Mustami (2016) emphasized that misconceptions are not limited to students alone but are also common among teachers. Such misunderstandings may arise from inadequate instructional practices and the use of teaching media that fail to adequately represent scientific concepts. In addition, the way knowledge is constructed in learners' minds may also contribute to the persistence of misconceptions. Osman, BouJaoude, and Hamdan (2017) reported that preservice teachers demonstrated misconceptions regarding global warming, the greenhouse effect, and ozone layer depletion, largely due to their prior scientific beliefs.

Mustami (2016) further noted that some biology textbooks contain conceptual inaccuracies, meaning that both teachers and students who rely on these materials may develop or reinforce misconceptions. These misconceptions are often deeply rooted and resistant to instructional change, persisting even after formal teaching. Toth, Ludvico, and Morrow (2014) explain that misconceptions form part of an interconnected knowledge system that learners use to interpret their experiences, often developing before and during the early stages of schooling.

Within biology education, genetics has received considerable attention due to the persistent difficulties students face in understanding its concepts and the associated misconceptions (Mustami, 2016). Research has shown that both primary and secondary school learners experience significant challenges in areas such as cell biology and genetics (Al Musawi et al., 2017; Yuliati, Riantoni, & Mufti, 2018). However, there is still limited literature providing detailed investigations into student misconceptions specifically related to the cell.

Benzer and Ünal (2021) noted that previous studies have consistently reported learners' difficulties in understanding cell division. Since cell division forms the foundation for genetics, reproduction, growth, development, and molecular biology, misconceptions in this area have wide-ranging implications for biology learning. In fact, many students and even teachers consider topics such as genes, DNA, chromosomes, and cell division to be particularly challenging (Astutik & Prahani, 2018).

Evidence from conceptual understanding studies shows that learners often retain misconceptions even after instruction, continuing to use non-scientific explanations alongside or instead of accepted scientific ideas (Benakli et al., 2017). Arabacioglu and Unver (2016) attributed some of these difficulties to learners' inability to distinguish between processes such as replication, synapsis, and disjunction, and to correctly identify whether these occur in mitosis, meiosis, or both. Additional misconceptions include confusion between chromatids and chromosomes, as well as between replicated and unreplicated chromosomes. These challenges are particularly concerning for educators, as understanding cell division is fundamental to grasping growth, development, reproduction, and genetics (Astutik & Prahani, 2018).

Astutik and Prahani (2018) found that research on problem-solving in genetics indicates students often hold misconceptions about the stages of meiosis. The proper organization of numerous concepts in cell biology may, in fact, rely heavily on the depth of students' understanding of cell division. Similarly, Benakli et al. (2017) emphasized that learners frequently demonstrate misconceptions and insufficient knowledge regarding chromosome behavior and the transfer of genetic material during cell division. These misunderstandings, in turn, contribute to broader conceptual difficulties in genetics.

Toth, Ludvico, and Morrow (2014) reported that even prospective science teachers frequently hold misconceptions, particularly regarding genes and chromosomes, as evidenced through analyses of their written explanations and drawings. The same study also drew attention to major advancements in genetics and biotechnology, including the Human Genome Project, genetically modified organisms, cloning, gene therapy, and research into genetic determinants of diseases. Despite the importance of these developments, public understanding of them remains limited, which raises significant societal concern (Kiliç & Sağlam, 2014). For example, genetically modified organisms are often viewed as potentially harmful to human health and the environment, even though they also present notable benefits. This has resulted in conflicting opinions, including among experts (Astutik & Prahani, 2018). Toth, Ludvico, and Morrow (2014) therefore argued that a basic level of scientific literacy is necessary for society to make informed decisions on such controversial issues, and that educators play a key role in effectively communicating this knowledge.

Persistent misconceptions among learners create major obstacles to understanding biological concepts and can hinder further learning. When these initial misconceptions are not addressed, students may struggle to grasp new ideas introduced in class or rely on memorisation for examinations, only to revert to their prior incorrect understandings outside the classroom (Özmen, 2004). Recent research on students' understanding of core life science concepts shows that meaningful learning is difficult unless prior misconceptions are identified and corrected, or students undergo conceptual change. Consequently, addressing misconceptions is a critical part of the learning process. It is widely recognised that students enter biology classrooms with a range of misconceptions, often grounded in personal beliefs and everyday observations.

Methods

Study Design and Setting

A convergent parallel mixed-methods design study was conducted at Bonzo Kaku Senior High School, Ellembele District, Ghana. The district is characterized by rural settlements and growing community education initiatives.

Population and Sample Size

The target population consisted of all form three (3) students at Bonzo Kaku Senior High School. Sample size Formula Adopted from Yamane (1967); Sample Proportion Formula adopted from Amofa (2025). So, the calculated sample size using Yamane's formula for a population of 450 with a margin of error of 5% is approximately 212.

The sample size was determined using Yamane's (1967) formula, which yielded a total of 212 students drawn from the population of 450. This sample size was considered adequate to ensure representativeness while maintaining feasibility for data collection and analysis.

$$n = \frac{N}{(1+(e)2}$$

Where:

- n = Sample size
- N = Population size
- e = Margin of error (expressed as a decimal, for example, 0.05 for 5%)

Using this formula, the sample size for a population of 450 with a margin of error of 5%.

Given:

- N=450
- e=0.05

Plugging in the values:

$n = \frac{450}{(1+450)(0.05)2}$

$n = 211.76n \approx 212$

Sample Proportion Formula Used: $\frac{\text{Sample Frame}}{\text{Total Population}} \times$ Sample size

The sample size for this study was determined using Yamane's (1967) formula, while the sample proportion was guided by Amofa (2025). Applying Yamane's formula to a population of 450 students with a 5% margin of error produced an approximate sample size of 212 students.

Data Collection Instruments and Procedures

The study utilises test as one of the principal instruments in collecting data on students' academic performance in Genetics. Two tests were used for collecting data which were pre-intervention and post intervention tests. The researcher did not used an existing test by any testing agency but designed a new test known as Genetics Achievement Teacher Made Test (GATMT). The content of the two tests and difficulty level were the same, but the questions were different. The researcher used closed-ended questionnaires adapted from existing validated tools which were on a 5 Likert-scale type, to collect quantitative data. The researcher carried out a semi-structured face-to-face interview with the respondents in a focus group discussion to obtain data on their views about their attitudes toward the learning of Genetics using PhET interactive simulations and hands-on laboratory experiments.

Variables and Measures

The questionnaire is divided into four sections:

Section A: Students' Biographical Data

Section B: Causes of Students' Misconceptions in Genetics

Section C: Students' Interest in Using PhET and Laboratory Experiments to Teach Genetics

Section D: Students' Perception of Using PhET and Experiments to Teach Genetics

Data Analysis

Analytical techniques used for data analysis were descriptive statistics, one-sample t-test, paired sample t-test, two-way ANOVA, and thematic analysis, using SPSS version 26.

Ethical Considerations

Approval for this study was obtained from the University of Education, Winneba ethical review Board (UEWERB) with ethical clearance reference number-UEWC/33. Participation was voluntary, with confidentiality.

Results

Table 7 : *Demographic Information on Participants*

Table 8: *Wilcoxon Rank Test Results*

Table 9: *Item by Item Analysis Results on Students Multiple-Choice Items*

Table 10: *Observed Students' Misconceptions and Corresponding Scientific Conceptions in Genetics Using Their Subjective Items*

Table 11: *Causes of Students Misconception in Genetics*

Table 20: *Summary of the Results*

Table 7 : *Demographic Information on Participants*

Variable	**Category**	**Counts**	**Percent**
Gender	Female	145	68%
	Male	67	32%

	Total	**212**	**100%**
Age	17-18	67	32%
	15-16	142	67%
	19 Years and Above	3	1%
	Total	**212**	**100%**
Residential Status	Boarding	146	69%
	Day	66	31%
	Total	**212**	**100%**
Parental Level of Education	No Formal Education	26	12%
	Primary	55	26%
	Secondary	93	44%
	Tertiary	38	18%
	Total	**212**	**100%**

From the descriptive statistics as presented in Table 7, majority of the respondents were females (68%) while males represented only 32%. In terms of age, most students were between ages 15 – 16 years (67%) followed by those aged 17 – 18 years (32%). Only one responded (1%) was 19 years or above. When it comes to residential status, 69% of the respondents were boarding students, while 31% were day students. For parental level of education, a large proportion of the students (44%) had parents with only secondary education while 26% had parents with primary education. A smaller number of students had parents with no formal education (12%) or tertiary education (18%).

Table 8: ***Wilcoxon Rank Test Results***

	Expected Median	Observed Median	Diff.	W	P	Effect Size
Pre-test	25	14	-11	0	< .001	-1.00
Prelab Skills	5	3	-2	0	< .001	-1.00

Note. Effect size was computed using Rank Biserial Correlation (RBC)

From the Wilcoxon Rank test results as presented in Table 8 above shows that there is a statistically significant large difference between the observed pre-test median score (Median = 14, SD = 4.43) and the expected median score (Median = 25), W = 0, p < .001. Out of the overall score of 50, the average performance was 14 far below the cut-score of 25. This shows that students performance were far below average performance, indicating a serious misconception among the students regarding the topic. The effect size, calculated using the rank biserial correlation (RBC), was -1.00, suggesting a very large difference between the median cut-score and the observed median. This means, if a student is selected at random, there is a 100% chance that the student has a misconception about genetics, indicating a very wide gap between students' current knowledge and what is expected.

For the pre-laboratory skills, the Wilcoxon test also showed a statistically significant large difference between the observed median score and the expected median (W = 0, p < .001). Out of the overall rating of 10, the observed average rating was 2 far below the baseline rating of 5, indicating a strong misconception about genetic concept. This means most of the students do not have practical knowledge on genetics. They cannot translate their knowledge into a practical hands-on in the laboratory. The effect size was again -1.00 confirming that there is a very wide gap in students laboratory skills related to genetics.

4.1.1 Identification of conception and misconception by item-by-item analysis

After the results of the Wilcoxon Signed-Rank Test were obtained, an item-by-item analysis was further conducted to identify the specific genetics concepts where students demonstrated either adequate understanding or misconceptions. For the multiple-choice items, descriptive statistics were employed to compute the frequency and percentage of learners who answered each item correctly and incorrectly.

A benchmark of 50% was adopted in determining students' level of understanding. Items with less than 50% correct responses were classified as areas of misconception, whereas items with 50% or more correct responses were considered areas where students demonstrated adequate conception of the concepts assessed. To again validate this classification, a chi-square goodness-of-fit test was performed to determine whether the observed differences between correct and incorrect responses were statistically significant. A p-value greater than .05 indicated that the difference between correct and incorrect responses was not statistically significant, suggesting no strong evidence of misconception among students on that item while a p-value less than .05 indicated a presence of misconception.

This threshold is supported by psychometric standards and test development literature, where a 50% success rate is often regarded as the minimum indicator of acceptable item mastery, particularly in short classroom-based assessments (McCrossan et al., 2022; Boateng et al., 2018; Mccowan & Mccowan, 1999). Additionally, distractor analysis suggests that items missed by more than half of the test-takers typically indicate cognitive confusion or instructional gaps (Sexton et al., 2006).

For the subjective items, observed students' misconceptions were identified. The number of students with each misconception was counted and their corresponding percentages computed. These were then compared with the correct scientific conceptions. The frequency and percentage of students who demonstrated the correct scientific understanding were also computed. Tables 9 and 10 below present the results.

Table 9: ***Item by Item Analysis Results on Students Multiple-Choice Items***

No.	Question	Correct (n, %)	Incorrect (n, %)	Diff.	p-value	Remarks
1	What is Genetics?	193 (91%)	19 (9%)	82 %	< .001	✓ Significant
2	Who is known as the father of modern genetics?	183 (86%)	29 (14%)	72 %	< .001	✓ Significant
3	What are alleles?	59 (28%)	153 (72%)	-44 %	< .001	✓ Significant
4	What does the term 'phenotype' refer to?	90 (42%)	122 (58%)	-16 %	0.033	✓ Significant

5	Which of the following is a homozygous genotype?	31 (15%)	181 (85%)	-70%	< .001	✓ Significant
6	What is the function of mRNA in genetics?	46 (22%)	166 (78%)	-56%	< .001	✓ Significant
7	Which of the following is NOT a Mendelian principle of inheritance?	92 (43%)	120 (57%)	-14%	0.063	✗ Not Significant
8	What is a Punnett square used for?	88 (42%)	124 (58%)	-16%	0.016	✓ Significant
9	In a dihybrid cross between two heterozygous parents (AaBb)...	24 (11%)	188 (89%)	-78%	< .001	✓ Significant
10	What is genetic linkage?	141 (67%)	71 (33%)	34%	< .001	✓ Significant
11	Which molecule carries the genetic code from DNA to ribosome?	97 (46%)	115 (54%)	-8%	0.243	✗ Not Significant
12	What process involves separation of homologous chromosomes in meiosis?	51 (24%)	161 (76%)	-52%	< .001	✓ Significant
13	Which type of mutation changes a single nucleotide?	42 (20%)	170 (80%)	-60%	< .001	✓ Significant
14	What is the role of tRNA during translation?	63 (30%)	149 (70%)	-40%	< .001	✓ Significant
15	What is a karyotype?	70 (33%)	142 (67%)	-34%	< .001	✓ Significant
16	What describes an organism with two identical alleles?	92 (43%)	120 (57%)	-14%	0.063	✗ Not Significant
17	Which disorder is caused by an extra chromosome 21?	41 (19%)	171 (81%)	-62%	< .001	✓ Significant
18	Probability of homozygous recessive offspring from two heterozygotes?	76 (36%)	136 (64%)	-28%	< .001	✓ Significant

19	Which is an example of codominance?	97 (46%)	115 (54%)	-8%	0.243	✕ Not Significant
20	What does a pedigree chart show?	68 (32%)	144 (68%)	-36%	< .001	✓ Significant

Note. The p-values were computed using a binomial test at 0.05 significance level. ✓ significant misconception, ✕ no significant misconception.

Table 10

Observed Students' Misconceptions and Corresponding Scientific Conceptions in Genetics Using Their Subjective Items

No.	**Students' Misconceptions**	**Freq. (%)**	**Scientific Conceptions**	**Freq. (%)**
1	Students believed that codominance refers to blood groups producing brown-eyed offspring.	192 (91%)	Codominance is a pattern of inheritance where both alleles are fully expressed in a heterozygous organism without one being dominant over the other.	20 (9%)
2	Students believed that a Punnett square is a circular structure of organisms.	187 (88%)	A Punnett square is a diagram used to predict possible genetic combinations of offspring.	25 (12%)
3	Students believed that genetic engineering only describes genetic information or types.	190 (90%)	Genetic engineering involves the direct modification of an organism's DNA to produce desired traits.	22 (10%)
4	Mutation was referred as a rare genetic disorder such as cystic fibrosis and other diseases.	195 (92%)	Mutation is a permanent change in the DNA sequence that may occur naturally or be caused by external factors such as radiation or chemicals.	17 (8%)
5	DNA was explained to be used to determine whether a person is positive or negative and to assess knowledge.	192 (91%)	DNA is a double-helix molecule made of nucleotides that stores genetic information used in protein synthesis.	20 (9%)
6	Meiosis was explained as joining of organisms from parents to form offspring.	179 (84%)	Meiosis is a type of cell division that produces four haploid gametes with half the number of chromosomes.	33 (16%)

7	Traits acquired during an organism's lifetime was explained to be inherited by offspring.	188 (89%)	Traits are inherited characteristics passed from parents to offspring through genes.	24 (11%)
8	Students believed that a person's blood type can change due to age, diet, or medical treatment.	183 (86%)	Blood group is genetically determined by alleles A, B, and O, inherited from parents and does not change.	29 (14%)
9	Students also believed that blood type B is formed by mixing blood types A and B like paint.	189 (89%)	Human blood groups include A, B, AB, and O, determined by inherited alleles, not mixing.	25 (11%)

From the item-by-item analysis results as presented in Table 9, most learners got the basic questions right. For example, 91% correctly answered "What is Genetics?" and 86% knew who is called the father of modern genetics. But for many of the other questions, the number of correct answers dropped. Only 28% knew what alleles are, and 42% understood the meaning of "phenotype." Just 15% could select out a homozygous genotype, and only 11% got the phenotypic ratio question right in a dihybrid cross. When it came to mRNA and tRNA, only 22% and 30% answered those correctly.

Many learners also had trouble with questions on Mendelian genetics and genetic tools. About 43% could tell which principle was not Mendelian and 42% knew what a Punnett square is used for. Only 32% could read a pedigree chart. Other areas such as meiosis (24%), mutations (20%) and Down syndrome (19%) also showed low scores. These results show that many learners did not understand key ideas in genetics, and it may point to some teaching challenges in these areas.

From the above, these findings suggest that although students may have memorized basic definitions, their understanding of more applied and abstract genetic concepts remains weak. This aligns with the Wilcoxon W Test result highlighting a significant misconception in knowledge about Genetics. This underscores the urgent need for pedagogical reforms that emphasize conceptual clarity, practical engagement and the use of appropriate instructional resources.

When it comes to essay item analysis as presented in Table 10, most students got the basic questions wrong. For example, 192 students representing 91% could not answer the question *"What is Codominace in Genetics?"* while 20 students representing 9% were able to explain it. Only 25 students amounting to 12% knew what a punnet square is, and 187 students representing 88% were unable to explain the meaning of a *"punnet square."* Just 10% of the students could explain the meaning and importance of genetic engineering, and 90% of the learners got it wrong. When it came to the meaning and examples of mutation, only 8% of students were able to answer correctly and 92% struggled to answer it correctly. This situation calls for an urgent need for pedagogical reforms that emphasize conceptual clarity, practical engagement, and the use of appropriate instructional resources. Targeted interventions such as the use of models, simulations, and inquiry-based approaches could help bridge the gap between theoretical content and students' comprehension.

Table 11: ***Causes of Students Misconception in Genetics***

No.	Statement	Mean	SD	Agree	Neutral	Disagree	SS
1	The abstract nature of genetics leads to misunderstanding.	3.54	1.07	158 (75%)	24 (11%)	30 (14%)	60.38
2	Lack of proper instructional media in schools contributes to misconceptions in genetics.	3.62	1.02	181 (85%)	16 (8%)	15 (7%)	78.77
3	Genetics concept is tedious and difficult to comprehend.	3.56	1.05	172 (81%)	21 (10%)	19 (9%)	72.17
4	Genetics terminologies (gene, chromosome, allele) are often confusing.	3.62	1.02	180 (85%)	9 (4%)	23 (11%)	73.58
5	Misconceptions about genetics are influenced by media portrayals.	3.5	1.08	161 (76%)	17 (8%)	34 (16%)	59.91
6	Textbooks do not adequately explain genetics concepts, leading to misconceptions.	3.62	1.02	182 (86%)	9 (4%)	21 (10%)	75.94
7	Lack of practical laboratory experiences negatively affects understanding of genetics.	3.64	1.00	187 (88%)	6 (3%)	19 (9%)	79.25
8	Genetics is difficult because it is not directly observable without special instruments.	3.65	1.00	191 (90%)	2 (1%)	19 (9%)	81.13
9	Inadequate teaching methods lead to misconceptions in genetics.	3.65	1.00	191 (90%)	8 (4%)	13 (6%)	83.96

Total Mean 32.4/9 = 3.6 & Total SD 9.26/9 = 1.02

From the descriptive statistics results as presented in Table 10, the sentiment score results indicate that the causes of students' misconceptions include inadequate teaching methods (191, 90%), lack of special laboratory instruments to observe genetics (191, 90%), lack of practical laboratory experience (187, 88%), inadequacy of textbooks to explain genetic concepts effectively (182, 86%), confusing genetics terminologies such as gene, chromosome, and allele (180, 85%), lack of proper instructional media in the school (180, 85%), difficulty in comprehending genetics concepts (172, 81%), misconceptions influenced by media portrayals (161, 76%), and the abstract nature of genetics (159, 75%).

From the above, it can be said that the most prominent cause of misconception is inadequate teaching methods (191, 90%). This indicates that instructional strategies significantly influence students' understanding. This suggests that traditional approaches are not effective in fostering deep comprehension of genetic concepts. Lack of special laboratory instruments (191, 90%) and lack of practical laboratory experience (187, 88%) closely follow, highlighting the importance of hands-on learning in genetics. These factors indicate that theoretical explanations alone may not suffice, and students require tangible engagement with genetic processes to solidify their understanding. The fact that both factors hold nearly equal weight suggests that even when students have access to laboratories, the absence of specialized instruments still hinders effective learning.

Inadequate textbooks (182, 86%) are another important factor, indicating that available biology books are not sufficient in explaining genetics in an accessible manner to students. This highlights the need for hands-on laboratory activities rather than depending on books. Additionally, confusing terminologies (180, 85%), such as gene, chromosome, and allele, were cited by students as a challenge. This prevents them from developing interest in the topic. Lack of proper instructional media (180, 85%) reinforces the role of teaching aids in simplifying complex biological concepts. Without appropriate media, abstract ideas may remain difficult to grasp, leading to misconceptions. Difficulty in comprehending genetic concepts (172, 81%) further emphasizes the inherent complexity of the subject matter. Also, misconceptions influenced by media portrayals (161, 76%) and the abstract nature of genetics (159, 75%) contribute to the confusion. From the above findings, it can be concluded that there is a need for simulation and laboratory hands-on experiences to bridge theory and practice. Experiential forms of learning will help learners move from theory to practice and reduce their misconceptions.

Table 20: ***Summary of the Results***

Research Question / Hypothesis	Key Finding	Conclusion
RQ1: What conceptions and misconceptions do students have about genetics?	Most students had difficulty understanding genetics concepts such as allele, genotype, phenotype and Punnett square. Many students failed items that required interpretation and application of concepts.	Students' misconceptions were linked to poor conceptual understanding and inability to connect genetics concepts to practical situations.
RQ2: What are the causes of students' misconceptions and poor performance in genetics?	Students reported that genetics concepts are abstract and difficult to understand. Lack of teaching materials, practical activities and clear explanations contributed to their poor understanding.	Students' misconceptions and poor performance were caused by abstract teaching, inadequate practical exposure and limited instructional resources.

Key Findings

1. The study found that students demonstrated stronger performance in recall-based aspects of genetics compared to application-based tasks. Most students were able to define genetics and correctly identify Mendel as the father of modern genetics. However, performance declined when questions required

conceptual application and interpretation. Difficulties were evident in the use and understanding of key terms such as allele, genotype, phenotype, and Punnett square. Many students were unable to correctly interpret genetic crosses or explain the roles of mRNA and tRNA. Performance was particularly weak in dihybrid cross items, where only a small proportion of students arrived at the correct phenotypic ratio. The pattern indicates that learning was largely limited to memorisation rather than conceptual understanding and application.

2. Also, the study found several contributors causing students misconception in genetics. Most of the students indicated that genetics is difficult due to its abstract nature. They reported challenges in relating the content to observable or real-life phenomena. A lack of instructional materials and limited practical activities were also identified as contributing factors. The dominant instructional approach was described as theoretical, with minimal opportunity for hands-on engagement. Some students indicated that they had never observed laboratory models or visual representations of structures such as chromosomes. This limited their ability to construct mental models of genetic processes and contributed to their difficulty in understanding the subject matter.

Conclusion

The findings indicate that students' difficulties in genetics are largely associated with the abstract nature of the subject, limited instructional resources and insufficient practical engagement during teaching. These factors contributed to weak conceptual understanding, particularly in areas involving genetic crosses and molecular processes.

Recommendations

1. This study revealed that students' misconceptions in genetics are not necessarily due to intellectual weakness, but rather the overly abstract and exam-oriented manner in which genetics is traditionally taught. Instruction that begins with technical terms and theoretical constructs often alienates learners, especially when they are unable to relate the content to everyday experiences. It is therefore recommended that teachers adopt a context-driven, constructivist approach by introducing genetic concepts through familiar, relatable scenarios before progressing to scientific terminology. Anchoring instruction in real-life examples such as familial resemblance or observable inheritance traits can scaffold students' understanding and promote meaningful learning that lasts beyond assessment periods.
2. The analysis revealed that inadequate teaching strategies, limited access to visual and laboratory resources, confusing scientific terminology and insufficient textbook clarity are key contributors to students' poor performance and persistent misconceptions in genetics. To address these structural limitations, it is recommended that teacher professional development programs be intensified and made practical. Specifically, science educators should be trained regularly in learner-centered and multimodal instructional methods that make abstract content more concrete. These capacity-building efforts should move beyond theoretical workshops and include hands-on modelling, peer learning, and resource improvisation techniques that reflect the realities of under-resourced classrooms.

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