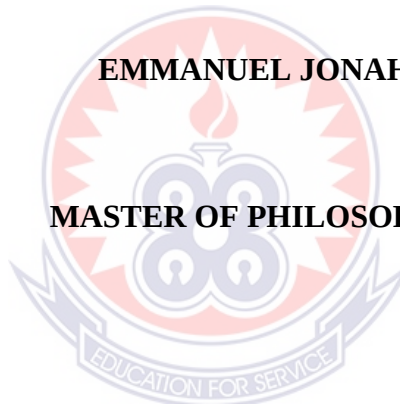


UNIVERSITY OF EDUCATION, WINNEBA

**Senior high school biology students' literacy, perceptions, and attitudes towards
biotechnology**

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MASTER OF PHILOSOPHY



UNIVERSITY OF EDUCATION, WINNEBA

**SENIOR HIGH SCHOOL BIOLOGY STUDENTS' LITERACY,
PERCEPTIONS, AND ATTITUDES TOWARDS BIOTECHNOLOGY**



**A Thesis in the Department of Biology Education,
Faculty of Science Education submitted to the school of
Graduate Studies in partial fulfilment
of the requirements for the award of the degree of
Master of Philosophy
(Biology Education)
in the University of Education, Winneba**

JANUARY, 2025

DECLARATION

Student's Declaration

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

SIGNATURE :.....

DATE:.....

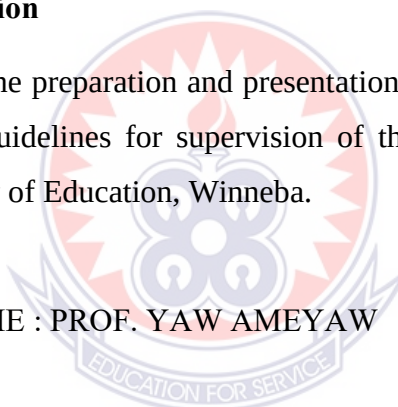
Supervisor's Declaration

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

SUPERVISOR'S NAME : PROF. YAW AMEYAW

SIGNATURE :.....

DATE:.....



DEDICATION

I dedicate this work to my parents and family for their kind support of my education,
as well as all my loved ones.



ACKNOWLEDGEMENTS

I am very grateful to the Almighty God for the vision, strength, and wisdom that it took this work to be successfully accomplished. My sincere thanks go to my supervisor, Prof. Yaw Ameyaw, who unreluctantly took time to guide and make the necessary corrections throughout the study despite his tight schedule. Finally, I am grateful to my colleagues and friends, who supported me in diverse ways throughout the project.



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ABSTRACT

This study investigated the literacy, perceptions, and attitudes towards the study of biotechnology among Form Three biology students in selected Senior High Schools in the Prestea/Huni-Valley Municipality of Ghana. A mixed-method approach was employed, utilizing questionnaires, tests, and interviews to collect data from a sample of 155 students and 3 teachers. Students' perceptions of biotechnology encompassed ethical considerations, risks, benefits, and religious and moral issues. Students' attitudes toward biotechnology applications, acceptance based on ethics and environmental impact, and purchase and use of biotechnology products were also examined. The study found varying levels of biotechnology literacy among students: nominal level ($M = 5.22$, $SD = 2.652$), functional scientific literacy ($M = 3.85$, $SD = 1.552$), conceptual level ($M = 3.68$, $SD = 1.902$), and multidimensional level ($M = 1.92$, $SD = 1.710$). These very low mean scores highlight a significant gap in students' understanding of biotechnological concepts and their applications. Differences were observed based on gender for the nominal level ($M = 1.331$, $p = .013$) and functional scientific literacy ($M = 0.799$, $p = .011$). Pearson's correlational analyses revealed insignificant and weak positive relationships between students' perceptions of biotechnology and their literacy scores ($r = 0.022$, $p = 0.791$) and between students' attitudes towards biotechnology and their literacy scores ($r = -0.077$, $p = 0.355$). The findings suggest a need for targeted interventions to enhance biotechnology education, addressing literacy levels, shaping perceptions, and fostering informed attitudes. Recommendations include incorporating hands-on learning experiences, promoting critical thinking, and engaging students in discussion on the societal implications of biotechnology. Further research is suggested to explore the impact of educational strategies on students' biotechnology literacy and performance. The study contributes to the understanding of factors influencing biotechnology education in Ghana and provides insights for improving teaching and learning in this field.

CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter introduces the study by discussing the background to the study, the statement of the problem, the purpose of the study, research objectives, research questions, significance of the study, delimitation, limitations, abbreviations, and organization of the study.

1.1 Background to the Study

Biotechnology has emerged as a significant and rapidly advancing field with applications across various domains, including health, food production, agriculture, environment, industry, and more across the globe (Dawson & Soames, 2006).

According to Bruschi et al. (2011), biotechnology is a socio-scientific subject that has been advancing in recent years and is encountered in nearly all fields, contributing to solving global challenges. In Ghana, biotechnology plays a crucial role not only in healthcare and environmental solutions but also in food production through genetic modification. However, the field of biotechnology is fraught with controversies and public concerns, particularly regarding issues such as stem cells, cloning, gene therapy, and genetically modified crops.

The Ghanaian Ministry of Education emphasizes the importance of fostering thinking skills, living skills, and career prospects among students (CDD, 2014). Biotechnology is included as a subtopic within the biology stream, aiming to enable students to appreciate biology's relevance to society and develop a scientific approach to problem-solving. However, despite its inclusion in the curriculum, there exists a negative trend in students' interest in science, both globally and in Ghana, especially in the Prestea/Huni-Valley Municipality.

As students progress through the educational system, their enthusiasm for science tends to wane, making it essential to explore the attitudinal constructs that affect their cognitive learning (Aikenhead, 2004). Students' perceptions and attitudes toward biotechnology processes, applications, and products are often unclear, leading to fear and uncertainty in the public, particularly in regions like the Prestea/Huni-Valley Municipality in Ghana.

It is believed that school education in science, especially biology, plays a major role in welcoming and dealing with the challenges of biotechnology (Schibeci, 2000). This is supported by the notion that there is a positive correlation between students' knowledge and attitudes towards biotechnology, as well as between students' perceptions and attitudes towards biotechnology (Ibrahim & Babayemi, 2010). Thus, science education, particularly in biology, is crucial in preparing students to address the challenges posed by biotechnology and contribute responsibly to public debates on biotechnological issues.

Furthermore, teenagers, especially students, represent a significant consumer market with unique preferences and behaviours (Gunter, Kinderlerer, & Beale, 1998, as cited in Kolarova, 2014). Therefore, it is essential to consider how biotechnology education may influence not only their scientific literacy, and performance but also their consumer choices and ethical considerations.

In summary, this study aims to assess students' literacy, perception, and attitudes toward biotechnology, with a focus on ethical and social dimensions, in the context of fostering informed decision-making about application and implication of biotechnology. It recognizes the importance of science education in preparing students to navigate the complexities of biotechnology and contribute responsibly to societal discussions and decision-making.

1.2 Statement of the Problem

Data on literacy levels, perceptions, and attitudes towards biotechnology among Senior High School biology students in the Prestea/Huni-Valley Municipality, Ghana, is scarce. Kolarova (2011) notes a lack of research on school-age students' understanding of modern biotechnology, and most especially Senior High School students.

In Ghana, Form Three biology students consistently perform poorly in biotechnology concepts, as evidenced by WAEC results (WAEC, 2020); and struggle with basic concepts like DNA structure, genetic engineering, and applications of biotechnology as noted by (Ogunleye, 2017). Also, a preliminary survey conducted by the researcher revealed that many students are unaware of biotechnology's role in foods like kenkey, bread, and yoghurt; and struggle to connect its applications to real life despite its introduction in Senior High Schools.

Research by Berg and Smith, (2014) and Yilmaz and Cavas, (2018), suggest that literacy levels, perceptions, and attitudes significantly impact students' academic performance and their ability to engage with biotechnological advancements.

The lack of data on students' literacy, perceptions and attitudes towards biotechnology in the Prestea/Huni-Valley Municipality creates a knowledge gap. This hinders their educational and career prospects; and limits societal progress by restricting informed decision-making and responsible applications of biotechnology. There is a pressing need to assess students' biotechnology literacy to address this gap and guide educational policies to improve their performance and future scientific engagement. Therefore, there is an urgent call for investigating the literacy, perceptions, and attitudes towards biotechnology among Form Three biology students in selected Senior High Schools in the Prestea/Huni-Valley Municipality.

1.3 Purpose of the Study

The purpose of this study is to investigate Form Three biology students' literacy, perceptions, and attitudes towards biotechnology in selected Senior High Schools in the Prestea/Huni-Valley Municipality.

1.4 Objectives of the Study

The objectives of this research were to:

1. assess biology students' biotechnology literacy levels.
2. identify the biology students' perceptions of biotechnology; its applications, and products.
3. identify attitudes towards biotechnology; its application, and products among students.
4. examine the co-relationship between students' perceptions and biotechnology literacy; and attitudes and biotechnology literacy.

1.5 Research Questions

This study addressed the following research questions:

1. What are the biotechnology literacy levels of the biology students?
2. What are the perceptions of biotechnology; its applications, and products among biology students?
3. What are the attitudes towards biotechnology; its applications, and products among biology students?
4. What are the co-relationships between students' perceptions and biotechnology literacy; and attitudes and biotechnology literacy?

1.6 Significance of the Study

This study will have a significant impact on Biotechnology education and research in the selected schools. The findings will also help teachers in the selected schools, to identify the areas that need improvement and further studies to better prepare students for the demands of the biotechnology industry and further professional biotechnology courses.

Again, the study will help improve science communication and outreach efforts aimed at increasing public understanding of biotechnology in the Prestea/Huni-Valley Municipality. Additionally, findings will be used to inform future research on scientific literacy in biotechnology and other related scientific fields since it is lacking in Prestea/Huni-Valley Municipality.

1.7 Delimitation

Delimitations are restrictions within the control of the researcher (Simons, 2011). The study was conducted in the three public Senior High Schools, namely St. Augustine's Senior High School, Huni-Valley Senior High School and Prestea Senior High Technical School found in Bogoso, Huni-Valley, and Prestea respectively, all located in the Prestea/Huni-Valley Municipality in the Western Region of Ghana. These schools were convenient in terms of accessibility, reachability, and familiarity as well as resource availability; all of these made it easier to get information from the respondents. The study also considered data from Category C public senior high schools only for a comprehensive study. The study considered only Senior High School Form Three biology students and subject teachers. This research again focused on Biotechnology as a unit under a section of the biology syllabus, and related units

because of its sensitivity and the importance of its applications and products in the 21st century.

1.8 Limitation

The small sample size reduces generalizability of the findings of this study, though the results may apply to respondents with similar characteristics. Additionally, reliance on self-reported data from students introduces potential biases. The use of questionnaires, tests, and interviews for data collection, as noted by Johnson and Christensen (2012), may limit the depth and quality of information gathered. Fear of failure among respondents during tests could also influence the findings.

1.9 Definition of Terms and Abbreviations

- SHS – Senior High School
- OECD – Organisation for Economic Cooperation and Development
- CDD – Curriculum Development Division
- GM – Genetically modified
- STEM – Science, Technology, Engineering, Mathematics
-

1.10 Organisation of the Study

This study was organised into five chapters. The first chapter introduced the study by discussing the background, statement of the problem, the purpose of the study, research objectives, research questions, the significance of the study, delimitation, limitations, abbreviations, and organization of the study.

The second chapter gave insight into the theoretical framework, conceptual framework, and empirical frame for the study and develop the topic, specific research problem, and other works related to the topic including gaps. The third chapter provided information on the methodology. This includes the research design, area of study, population,

sample selection, research instruments, the validity of instruments, reliability of the instruments, the procedure of data collection and analysis, and ethical considerations. The fourth chapter also provided information on the findings, analyses, and interpretations. The purpose is to summarize the collected data, how it was analysed, and then to present the results. The fifth chapter provided a summary of the study and conclusions drawn from the findings; recommendations based on the findings as well as suggestions. References and all documents used in this study, and other related materials were included as appendices.



CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter gives an overview of the literature related to study ‘using students’ literacy, perceptions, and attitudes to improve Form Three biology students’ performance in biotechnology in selected Senior High Schools’.

2.1 Theoretical Framework

According to Ajzen (2002), the Theory of Planned Behaviour suggests that human behaviour is shaped by three types of considerations: beliefs about the normative expectations, beliefs about the likely outcomes of one’s behaviour and the evaluations of such outcomes (behavioural beliefs). The more favourable the attitude and subjective norm and the greater the perceived control, the stronger should be the person’s intention to perform the behaviour in question (Ajzen, 2002). The original works of Ajzen (1991) elaborates that behavioural beliefs shape an individual’s attitude toward a particular action, normative beliefs influence the perception of social pressure (subjective norm), and control beliefs determine the sense of behavioural control. Collectively, these three factors contribute to the formation of behavioural intentions. In short, people tend to do as they please when given total control over their actions and inactions, using all available opportunities.

Beliefs that guide intention are often shaped by background factors such as personal experiences or cultural context. These manifest as behavioural beliefs (which form attitudes), normative beliefs (which create subjective norms), and control beliefs (which influence perceived behavioural control) (Ajzen, 1991; Bagozzi, 2007). Behavioural intention, often described as an individual’s motivational readiness to engage in a

behaviour, reflects the internal decision to exert effort toward performing that action (Ajzen, 1991; Benbasat & Barki, 2007).

The TPB has emerged as a valuable framework for understanding and predicting human behaviour in various contexts, including education. In the realm of Form Three biology education, particularly concerning biotechnology, the TPB offers insights into how students' attitudes, perceptions, and intentions shape their performance and engagement with the subject matter.

Numerous studies have highlighted the significance of attitudes in shaping students' academic performance and learning outcomes. In the context of biotechnology education, attitudes toward the subject play a crucial role in influencing students' motivation, interest, and willingness to engage with the material. Positive attitudes have been shown to be central to students' engagement with science, influencing both classroom learning and career aspirations (George, 2006; Osborne, Simon, & Collins, 2003).

Perceptions of biotechnology's relevance and importance in biology education also contribute significantly to students' academic performance. Subjective norms, referring to perceived social pressures to perform or engage in certain behaviours, further influence students' intentions and actions. Students who perceive biotechnology as essential for future careers or societal advancements are more likely to exhibit higher levels of engagement and achievement in biology.

Perceived Behavioural Control (PBC) is an additional determinant of human motivational intention which has been incorporated in TPB. PBC was added because individuals might have incomplete control over their intended behaviour, especially in unstable and uncontrolled external contexts (Bagozzi, 2007).

Perceived behavioural control in individuals (Form Three biology students) refers to their belief in their ability to grasp and apply biotechnological concepts. This belief greatly influences their academic performance, with those feeling confident about their understanding and application of these principles tending to achieve higher academic success. Essentially, students' confidence in mastering biotechnology significantly impacts their outcomes in biology studies.

Bagozzi (2007) argues that behaviour-change interventions typically focus on the main determinants of intention, such as attitudes, subjective norms, and perceived behavioural control. Changes in these three factors result in changes in behavioural intentions and given adequate control over the behaviour, the new intentions should be carried out under appropriate circumstances. Research indicates that intentions can be reliably predicted from attitudes, social pressures, and perceptions of control, and together with perceived control, these factors significantly account for variations in behaviour (Ajzen, 2002). While attitudes, norms, and control perceptions are thought to stem from related sets of salient beliefs, Ajzen cautions that the exact relationship between these belief structures and behaviour is still not completely understood. Teachers and researchers, therefore, apply the Theory of Planned Behaviour (TPB) framework to design interventions, such as immersive learning experiences like hands-on laboratory activities and visits to biotechnology facilities, aimed at enhancing biology students' performance in biotechnology.

In conclusion, the Theory of Planned Behaviour offers a comprehensive framework for enhancing Form Three biology performance in biotechnology through addressing attitudes, perceptions, and intentions, allowing Teachers to design effective interventions targeting these aspects to improve students' engagement, motivation, and academic achievement. Additionally, this study integrates insights from the Theory of

Attitude Formation; and Bybee's Theory of Scientific Literacy in assessing the biotechnology literacy levels of the sampled students and their gender, emphasizing the importance of understanding how attitudes develop and integrating scientific knowledge with real-world contexts for inquiry-based learning experiences.

2.2 Conceptual Framework

The graphical representation below depicts the conceptual framework of the study (Figure 1).

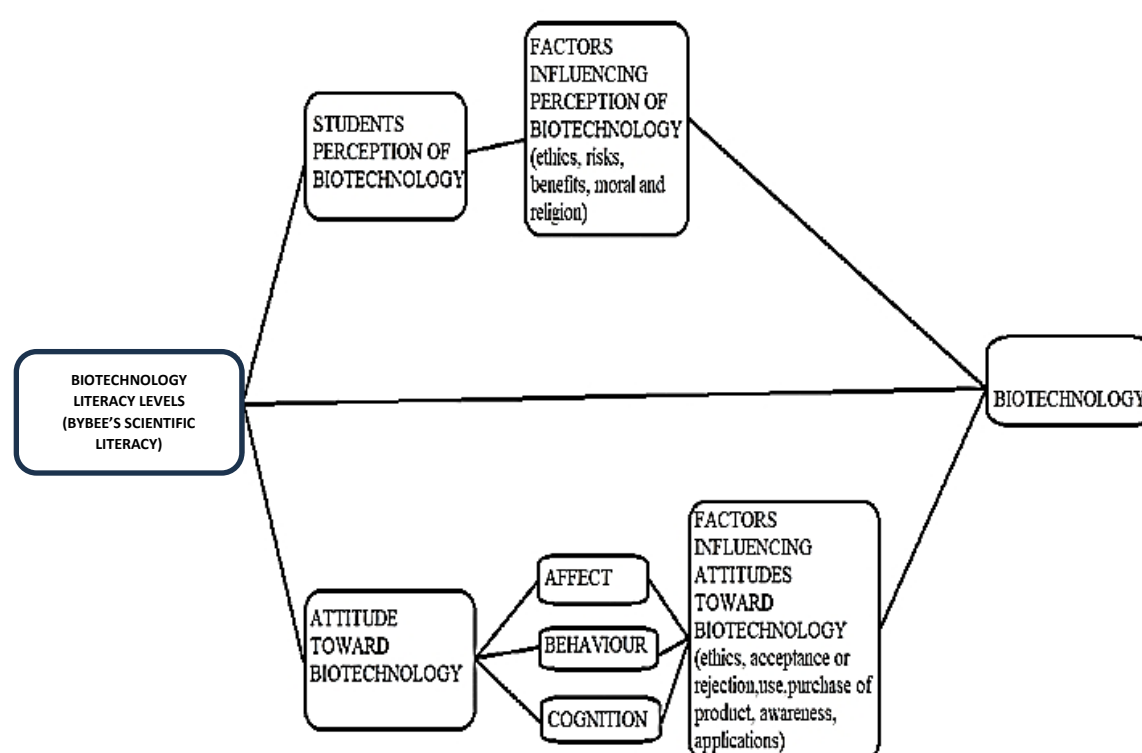


Fig. 1. Conceptual framework of the study

2.2.1 Attitude Towards Biotechnology

Attitudes toward biotechnology reflect students' beliefs, values, and emotional responses to biotechnological innovations. As highlighted by Fonseca, Costa, Lencastre and Tavares (2012a), attitudes play a crucial role in shaping students' engagement, decision-making, and behaviour in biotechnology education. Positive attitudes towards biotechnology are associated with openness to new ideas, willingness to explore

complex concepts, and active participation in learning activities, which improve performance.

To cultivate positive attitudes toward biotechnology, Teachers must create a supportive learning environment that encourages curiosity, inquiry, and experimentation (Fonseca et al., 2012a). Providing opportunities for hands-on engagement with biotechnology through practical experiments, case studies, and real-life examples can enhance students' understanding and appreciation of biotechnological concepts. Additionally, promoting critical thinking and reflection on biotechnological issues empowers students to form informed opinions based on evidence and reasoning, leading to the development of positive attitudes towards biotechnology (Fonseca et al., 2012a)

2.2.2 Attitude Models in Science Education Research

In biotechnology education research (BTER), “attitude” as a construct has not received the same depth of critical examination seen in behavioural or psychological sciences. Research in science education has often treated the concept broadly, referring to it simply as “attitude” without further elaboration (Potvin & Hasni, 2014b). When science education researchers discuss attitudes, they often rely on either the unitary or tripartite framework. However, the instruments created to measure students' attitudes toward science have historically focused on emotional or evaluative aspects, giving less attention to the behavioural and cognitive components described in the tripartite model (Koballa Jr & Glynn, 2007).

Several studies in biotechnology education research (BTER) have examined attitudes using either specific unitary models or more basic, undefined frameworks (Casanoves et al., 2015; Chen et al., 2016; Dawson & Schibeci, 2003; Kidman, 2009; Mowen et al., 2007; Prokop et al., 2007, as cited in Nordqvist & Johansson, 2019). A similar trend

can also be observed in related fields, such as investigations of public or consumer attitudes toward modern biotechnology (Magnusson & Hursti, 2002). When an “attitude” framework is not clearly defined, the research design typically reflects a unitary model, occasionally supplemented with a behavioural aspect. In the case of BTER, relatively few studies have adopted the tripartite approach by analysing the affective, behavioural, and cognitive dimensions independently (Nordqvist & Johansson, 2019).

2.3 Students’ Attitudes towards Biotechnology

Most studies in BTER report that students who possess greater knowledge about biotechnology also tend to show more positive attitudes toward its applications and products (Dawson & Schibeci, 2003; Klop et al., 2010, as cited in Nordqvist & Johansson, 2019). However, a smaller number of studies have challenged this trend, suggesting that content knowledge does not always significantly correlate with students’ attitudes toward biotechnology (Sorgo & Ambrozic-Dolinsek, 2009; Usak, Erdogan, Prokop, & Ozel, 2009, as cited in Nordqvist & Johansson, 2019). Therefore, findings about the relationship between content knowledge and attitudes towards modern biotechnology among students seem to be somewhat inconclusive.

Despite the inconsistencies, most research in BTER supports the idea that content knowledge is positively related to students’ attitudes toward biotechnology. However, some studies suggest that younger learners often view biotechnology less favourably than older students, which may be linked to their limited topic-specific or general science knowledge (Chen & Raffan, 1999; Dawson, 2006). Evidence from studies applying the unitary model also points to gender differences, with boys typically reporting more positive attitudes toward modern biotechnology than girls (Crne-

Hladnik et al., 2009; Finke & Kim, 2004; Prokop et al., 2007, cited in Nordqvist & Johansson, 2019).

A study of biology students using the tripartite model identified that boys had more positive attitudes than girls in general, especially on the cognitive and affective scales, even though behavioural attitudes were not gendered. Other studies suggest that any such differences will be content-dependent, in that boys and girls will respond differently to certain science content instead of responding to science in general (Potvin & Hasni, 2014b).

Correlation results between school performance and science attitude are contradictory. Others found no correlation (Morrell & Lederman, 1998; Willson, 1983, as cited in Nordqvist & Johansson, 2019), while others suggested that better school performance would evoke better attitudes (Potvin & Hasni, 2014). Yet, the global TIMSS results show the contrary, in which students of high-achieving nations are usually less enthusiastic about science (Osborne & Dillon, 2008). This has been referred to as the "attitude-achievement paradox," in which cultural expectations and difference between individual- and system-outcome variability could explain why good achievement is not necessarily followed by positive attitudes.

There is indication that pupils with more educated parents do not necessarily possess better attitudes towards science. In some studies, even the opposite is revealed and weak or slightly negative correlations (George, 2006; Papanastasiou & Papanastasiou, 2004; Telli, Brok, & Cakiroglu, 2010, cited in Nordqvist & Johansson, 2019) are noted. So far, no research has directly tested whether parental education or students' own school performance affects how they view biotechnology. What is clear, however, is that students who are more interested in science generally also have more positive attitudes

toward it (Tuan, Chin, & Shieh, 2005). Song (2009, as cited in Nordqvist & Johansson, 2019) found this was especially true for intrinsic attitudes, while interest had little effect on extrinsic ones. Overall, science education researchers agree that general interest plays an important role in shaping students' attitudes.

2.3.1 Present study

Although previous studies have typically viewed attitudes toward modern biotechnology as a single component, there is a strong rationale to consider the tripartite model as more suitable in this context. Biotechnology education inherently incorporates ethical and moral considerations, which are less prevalent in other areas of science such as chemistry or physics. Consequently, students are likely to hold more pronounced opinions and attitudes toward biotechnology specifically. Thus, it is proposed that the tripartite model, encompassing affect, behaviour, and cognition, would better capture the complexity of attitudes in this domain. While the attitude construct of biotechnology may include specific components, there may also exist a general attitude toward biotechnology that transcends these individual elements. In light of these considerations, the primary objective of this study is to empirically examine the attitudes of Form Three Senior High School biology students toward both traditional and modern biotechnology.

2.3.2 The concept of attitude formation

An attitude represents a predisposition to view or respond to something in either a favourable or unfavourable way. It develops out of the individual's values and belief systems and is reinforced through daily experiences. Thus, attitudes are constantly at play in how people interpret and react to the world around them. According to Bakanauskas, Kondrotiene, and Pukša (2020), from an early age, parents (or our external environmental influences) try to interpret and push forward what they consider

good or bad, right or wrong, or generally positive or negative. These evaluations are continuously shaped by the flow of information we encounter daily through different channels, ultimately influencing how we form perspectives on particular objects or issues (Bakanauskas et al., 2020). While attitudes have been examined for decades by scholars across various sciences, researchers in psychology, sociology, and marketing have, in recent times, revived interest in this study in various contexts (Bakanauskas et al., 2020). This reawakened interest is attributed, on a large scale, to globalization, which has not only opened up markets but also influenced consumer expectations and choices. Therefore, professionals in businesses now struggle with winning consumer attention, as consumers themselves are largely accountable for generating demand for most products and services (Bakanauskas et al., 2020). Meanwhile, others, like disease prevention and health care, are still under researched regarding how consumer attitudes are shaped, with what is known being confined to limited fields of investigation (Bakanauskas et al., 2020). This presents a fundamental question: what influences consumer attitudes towards products or services?

Bakanauskas et al. (2020) conceptualize attitude as a multifaceted and holistic phenomenon is founded upon psychological processes that unify an individual's beliefs and emotions towards an object, which can, in turn, influence their behaviour

In the 19th century, Bakanauskas et al. (2020) cited Allport (1935) when examining how scholars of his time defined the concept of attitude. Drawing on their interpretations and his own analysis, he described attitude as a neuropsychic readiness that prepared an individual for both mental and physical activity, essentially reflecting one's orientation toward a given value.

According to Bakanauskas et al. (2020), certain attitudes typically trigger responses that can be favourable or unfavourable, positive or negative, and may manifest as acceptance or rejection of an object. Such reactions can occur openly or subtly, consciously or unconsciously, rationally or irrationally. These early definitions already pointed to a strong link between attitudes and behaviour. Attitudes were not only framed as a complex evaluative response to objects but also as a predisposition to act as a “mental” or “motor” readiness to engage with an object perceived to hold value (Bakanauskas et al., 2020).

Later developments in studies on attitude broadened its definition. For instance, Bem et al. (1972), as cited in Bakanauskas et al. (2020), described attitude as how an individual’s perceives and reacts toward a particular object. Scholars from psychology and marketing have also emphasized the evaluative nature of attitude. Authors such as Lott and Lott (1985), Chaiken and Stangor (1987), Ajzen (2001), Hogg and Vaughan (2005), and Pratkanis, Breckler, and Greenwald (2014), cited in Bakanauskas et al. (2020), framed it as a “cumulative” or “acquired” evaluation, expressed as favourable or unfavourable judgments.

From a psychological perspective, attitude is viewed as a latent construct that shapes human decision-making and behavioural choices (Bakanauskas et al., 2020). Most definitions converge on three core elements: an evaluative process, a focus or object of evaluation, and the behavioural tendency that follows (Bakanauskas et al., 2020).

Together, these components illustrate how people form positive or negative orientations toward entities, combining beliefs and cognitive appraisals with behavioural intentions.

Evaluations are not formed in isolation but are intertwined with emotions and lived experiences (Bakanauskas et al., 2020). For this reason, other scholars, such as Edwards (1990) and Van Kleef, Van den Berg, and Heerdink (2015), as cited in Bakanauskas et

al. (2020), state that affective (emotional) and cognitive (knowledge- and experience-based) components are used to explain the concept of the attitude phenomenon.

From an affective (emotional) perspective, attitude can be understood as a person's emotional disposition toward an object, expressed through either positive or negative evaluations. These emotional responses involve distinct subjective experiences, physiological changes, expressive behaviours, and action tendencies (Bakanauskas et al., 2020). Since emotions are described as outcomes of empirical processes, the phenomenon of attitude is closely tied to empirical experience. Bakanauskas et al. (2020) explain that attitudes are guided by personal experiences, whether positive or negative, with the object being assessed. The cognitive aspect defines what a person knows, believes, or perceives about that object, based on both past experiences and new information. In this way, attitudes represent a combination of knowledge, feelings, values, and evaluations gathered over time, and they consistently reveal whether an individual's response toward an object is favourable or unfavourable.

Ito and Cacioppo (2001, as cited in Bakanauskas et al., 2020) describe attitude as a psychological state that develops through experience and guides how people respond to different situations. In this sense, attitude works like a readiness or predisposition that comes into play when specific circumstances arise. Many scholars, including Edwards (1990), Eagly and Chaiken (1993, 2007), Ajzen (2001), Fazio (2007), Schwarz (2007), Petty, Briñol and DeMarree (2007), and Gawronski and Bodenhausen (2007), agree that attitudes can be directed toward almost anything such as ideas, events, people, groups, products, or services. Because attitudes are always connected to an object of evaluation, different researchers have also used a variety of models to explain how they are formed and expressed. Scientific models help to explain how people form causal judgments about phenomena and how they respond to different

stimuli. Most of these models examine the links between emotions, cognition (experience), and behaviour (Bakanauskas et al., 2020). For instance, Rosenberg's (1956) expectancy–value model, as cited in Bakanauskas et al. (2020), defines attitude as an overall evaluation shaped by both expectations and the perceived value of outcomes. Similarly, the well-known three-component model, often referred to as the ABC model developed by Eagly and Chaiken (1993, cited in Bakanauskas et al., 2020), said the phenomenon of attitude is explained through the interfaces of three components: affective (feelings, emotions), cognitive (cognition-experience, knowledge), and conative (behavioural, act). By summarizing the theoretical interpretations of the concept of attitude presented in the literature analysed, it is possible to form a general definition of an attitude concept (Bakanauskas et al., 2020). As defined by Bakanauskas et al. (2020), Attitude is to be understood as an internal, typically invisible item stored in an individual's memory, and it is a summary judgment of some objects such as concepts, people, events, goods, services, ideas, or social processes. It is the psychological "umbrella" of an individual containing the beliefs, feelings, knowledge, experiences, expectations, values, and moral or social rules adopted on the basis of emotional, cognitive, and behavioral domains. In light of this, attitudes reflect the level of favourability or unfavorability of an object to an individual, and his unwillingness or willingness to act with respect to it. Extending this definition to the cognitive and affective levels, attitude is shaped by long-term experiences and manifests in particular contexts as an individual's internalized beliefs, positive or negative feelings, and perceptions. These, in turn, generate corresponding emotional responses toward objects, ideas, events, or problems, which may ultimately influence behaviour (Bakanauskas et al., 2020).

2.3.3 Attitude formation as a phenomenon of cognitive or affective factors

Research by the scientists who have studied attitude formation cited in Nordqvist and Johansson (2019) including Zajonc and Markus, (1982), Petty, Fabrigar and Wegener, (1997), Ajzen, (2001), Maio, Haddock and Verplanken, (2019), revealed the influence of cognitive and affective factors on attitude formation. Affective factors encompass emotions, beliefs, and the habits of a person, building emotional attitudes through personal judgments. The socialization and external influences build cognitive aspects, which affect attitudes through experience and familiarity with the environment and other people. Affective attitudes are motivated to a practical extent by an inside push or sentiment, while cognitive-built attitudes are built from external influences and socialization processes, i.e., the necessity for more biotechnology training.

After a study by Breckler (1984), Edwards (1990), and Eagly and Chaiken (1993), as cited by Nordqvist and Johansson (2019), the formation of attitudes is viewed as a multi-component process with cognitive, affective, and behavioural elements. The most frequently quoted model, the three-component or ABC model, explains attitude formation through these interrelated components of cognition (experience and knowledge), affective (emotions and feelings), and conative (behavioural tendencies).

2.3.4 The cognitive component (level) of the attitude formation process

The review of studies on attitude formation, as discussed in Nordqvist and Johansson (2019) and conducted by Breckler (1984), Ajzen (1985, 2001, 2005), Fishbein and Middlestadt (1995), Sanders (2010), and Hogg and Vaughan (2011), indicates that the cognitive dimension of attitude formation is shaped by factors such as personal experience, knowledge, information, beliefs, and opinions related to the object of the attitude. The cognitive aspect of attitude formation is moulded by an individual's perception, cognition, and beliefs regarding an object. It stems from direct experiences

and the assessment of received information, encompassing stored memories and newly acquired knowledge. This component is influenced by past exposure to communication and educational materials, shaping attitudes based on prior experiences. To enhance attitudes, it's essential to improve education on biotechnology through various sources of information and communication. The scientific literature in Ajzen, (2005), Oskamp and Schulz, (2014) cited in Nordqvist and Johansson (2019) found that One cannot separate information from the external environment which is the external stimuli from which it is derived (e.g. advertising, the internet, friends, family, social groups).

At the cognitive level of attitude formation, individuals assess objects using available information, which can be influenced by mass media and external stimuli. This evaluation includes weighing the advantages and disadvantages, often using measurable criteria. Negative information tends to have a stronger impact than positive data. Attitudes can change as individuals integrate new information and reevaluate their beliefs, a process guided by information integration theory.

2.3.5 The affective component (level) of the attitude formation process

The impact and influence of emotions on attitude formation continues to be a subject of research and is widely debated in assessing the process of attitude formation.

The biggest questions, however, arises out of the frequency of emotions used to influence others, whether they influence attitude formation, and how strong or long-lasting an attitude is when based on the emotional evaluation that elicits an instantaneous reaction to the object of attitude (Van Kleef, Van den Berg, & Heerdink, 2015 as cited in Nordqvist & Johansson, 2019). Attitudes driven by emotions can be difficult for individuals to consciously rationalize, as they arise from feelings, moral

convictions, and personal values, sometimes influenced by religious beliefs; and may vary depending on circumstances.

An analysis of the literature on attitude formation, as discussed by Ajzen (2001), Crano and Prislin (2006), Bohner and Dickel (2011), Chaiklin (2011), and Greenwald (2014) cited in Nordqvist and Johansson (2019), shows that emotional responses to an attitude object emerge particularly when the attitude is not grounded in conscious reasoning or factual evidence, but rather in emotional evaluation. In attitude formation, the emotional aspect, also known as the affective component, can elicit varying intensities of response based on specific beliefs. Essentially, at this level, attitudes form through emotional reactions to an object, evoking particular emotions and prompting corresponding actions - a key aspect of attitude development.

2.3.6 The conative component (level) of the attitude formation process

At the behavioural stage of attitude formation, attitudes are expressed through actions that show how people are likely to respond or interact with a particular object. This component reflects an individual's reaction and evaluation (whether favourable or unfavourable) toward the object in question (Ajzen, 2005). A person's behaviour may be influenced by their own opinions, knowledge, or understanding of the object of the attitude, as well as by observing how others behave towards that same object, person, or stimulus (a cognitive factor). In such situations, watching the behaviour of others can shape an individual's response, prompting them to act in a particular way toward the stimulus (Bem, 1972). The behavioural component of attitude therefore includes both verbal and non-verbal ways of expressing one's emotional responses and inclinations towards something and it is influenced by assessing one's knowledge or observing others' behaviour towards the object, leading to specific actions or reactions.

2.3.7 Attitude towards Biotechnology application in agriculture

Biotechnology application in agriculture has emerged as a promising solution to address global food security challenges, increase crop yields, and reduce environmental impacts. The public together with students' perception and acceptance of biotechnology in agriculture has been widely studied, revealing a complex interplay of factors shaping attitudes and behaviours. Several studies have identified key determinants influencing stakeholders' attitudes toward biotechnology application in agriculture, including knowledge and awareness, perceived benefits and risks, trust in regulatory agencies, and socio-cultural factors (Lusk & Sullivan, 2002).

One significant factor influencing attitudes towards biotechnology in agriculture is stakeholders' level of knowledge and awareness. Studies have shown that individuals with higher levels of scientific literacy tend to have more positive attitudes towards biotechnological innovations in agriculture, as they can better understand the underlying science and potential benefits (Frewer, Scholderer, & Lambert, 2003). However, misconceptions and misinformation about biotechnology may lead to skepticism or opposition among those with limited understanding.

How the benefits and risks associated with biotechnology in agriculture are perceived, also play a crucial role in shaping attitudes. Stakeholders have weighed the potential advantages of biotechnology such as increased crop yields, reduced pesticide use, and enhanced nutritional content against perceived risks such as environmental pollution, biodiversity loss, and unknown long-term effects on human health. Studies have found that individuals' risk perceptions are influenced by factors such as media coverage, personal values, and trust in scientific institutions (Hoban, Woodrum, & Czaja, 2017).

Trust in regulatory agencies and biotech companies significantly influences attitudes towards biotechnology in agriculture. Stakeholders' confidence in the safety and efficacy of biotech products is closely linked to their trust in regulatory agencies' ability to assess and monitor biotechnological innovations (Gaskell et al., 2006). However, concerns about industry influence on regulatory processes and conflicts of interest may undermine trust and contribute to public skepticism (Irwin & Wynne, 1996).

Socio-cultural factors such as cultural norms, religious beliefs, and socio-economic status also shape attitudes towards biotechnology in agriculture. Studies have shown that cultural values and ethical considerations influence individuals' perceptions of biotechnological innovations, with some communities expressing moral objections to genetic engineering and other biotech practices (Macnaghten & Urry, 2001). Additionally, socio-economic factors such as access to information and economic incentives may impact stakeholders' willingness to adopt biotech solutions in agriculture (Qaim & Kouser, 2013).

Attitudes towards biotech in agriculture are complex, influenced by factors like knowledge, perceived benefits and risks, trust in regulation, and socio-cultural aspects. Addressing these through targeted communication, engagement, and transparent regulation is crucial for fostering informed adoption. Future research should look into evolving societal values and tech advancements.

2.4 Acceptance of the Use of Biotechnology Products

In recent years, the field of biotechnology has witnessed significant advancements, offering innovative solutions to various societal challenges. Within the context of education, particularly in Form Three biology students' classrooms, understanding

students' attitudes towards the acceptance of biotechnology products is crucial for enhancing their performance and engagement with the subject.

Attitude towards the use of biotechnology products encompasses students' beliefs, perceptions, and preferences regarding the utilization of biotechnological innovations in various domains, including agriculture, healthcare, and environmental conservation. Research suggests that students' attitudes towards biotechnology product acceptance are influenced by several factors, including their level of scientific literacy, perception of the ethical implications, and awareness of the societal benefits and risks associated with biotechnological applications (Brossard & Nisbet, 2007).

Scientific literacy plays a fundamental role in shaping students' attitudes toward biotechnology product utilization and usage. Students with higher levels of scientific literacy tend to demonstrate a more favourable attitude towards biotechnological innovations, as they possess the necessary knowledge and understanding to critically evaluate the scientific evidence and potential applications of biotechnology products (Baram-Tsabari & Yarden, 2007). Conversely, students with limited scientific literacy may exhibit skepticism or apprehension towards biotechnology products, stemming from a lack of comprehension or misinformation about the underlying science.

Perception of the ethical implications associated with biotechnology products also influences students' attitudes toward patronage. Students who perceive biotechnological innovations as ethically sound and aligned with societal values are more likely to embrace the use of biotechnology products (Gaskell, Stare, Allansdottir, Allum, Castro, Esmer, & Wagner, 2017). Conversely, concerns about ethical considerations, such as environmental sustainability, animal welfare, and human

safety, can lead to reluctance or opposition to the adoption of biotechnology products among students.

Furthermore, students' awareness of the societal benefits and risks associated with biotechnology products shapes their attitudes toward usage. Students who recognize the potential of biotechnological innovations to address global challenges, such as food insecurity, disease prevention, and environmental conservation, are more inclined to support the utilization of biotechnology products (Siegrist & Hartman, 2019). Conversely, apprehensions about the perceived risks, including unintended environmental consequences, genetic modification controversies, and corporate control over agricultural practices, may contribute to skepticism or resistance towards biotechnology product acceptance among students.

In conclusion, biology students' attitudes toward using biotechnology products are influenced by scientific literacy, ethical perceptions, and awareness of societal impacts. To enhance their acceptance and engagement, targeted interventions promoting scientific literacy and ethical reasoning, alongside informed discussions about societal implications, are crucial. Teachers can empower students to critically evaluate and responsibly engage with biotechnology products, both academically and beyond.

2.5 Awareness of Biotechnology Applications

The level of awareness regarding biotechnology applications significantly influences individuals' attitudes toward these innovations.

Awareness of biotechnology applications encompasses knowledge about its various uses in healthcare, agriculture, industry, and environmental conservation (Siegrist, Keller, & Kastenholz, 2019). Higher levels of awareness are often associated with

more positive attitudes toward biotechnology, as individuals recognize its potential benefits and contributions to society. Several factors influence awareness of biotechnology applications, including education level, media exposure, and personal experiences (Nisbet & Markowitz, 2016). Educational initiatives, public outreach campaigns, and media coverage play significant roles in shaping students' perceptions and increasing awareness of biotechnological innovation.

Awareness of biotechnology applications has a direct impact on individuals' attitudes toward these technologies (Singer & Dana, 2016). Greater awareness is correlated with more positive attitudes, as individuals are better equipped to understand the potential benefits and risks associated with biotechnological advancements.

Effective communication strategies are essential for increasing awareness of biotechnology applications and fostering positive attitudes (Bubela & Li, 2018). Transparent communication about the science behind biotechnological innovations, their real-world applications, and their ethical considerations can help bridge knowledge gaps and address students' concerns, ultimately promoting greater acceptance and support that subsequently improves the performance.

The level of awareness regarding biotechnology applications plays a significant role in shaping attitudes toward these innovations. By implementing educational initiatives, engaging with the media, and promoting transparent communication, stakeholders most especially, teachers can enhance awareness and foster positive attitudes toward biotechnological advancements.

2.6 Purchase of Biotechnology Products

The acquisition of biotechnology products is intrinsically linked to individuals' attitudes towards them. Students' attitudes toward biotechnology products encompass perceptions of their safety, efficacy, and ethical implications (Gaskell et al., 2017).

Positive attitudes often stem from recognizing biotechnology products as innovative solutions to contemporary challenges. Conversely, negative attitudes may arise from concerns about health risks, environmental impacts, or ethical considerations.

Several factors shape students' attitudes and purchase behaviour of biotechnology products, including literacy levels, perceived benefits, and socio-demographic variables (Singer, Friedman & Kwon 2016). Positive attitudes correlate with a heightened willingness to engage with biotech products, particularly when students perceive tangible benefits and have confidence in their safety and reliability.

Attitudes toward biotechnology products directly influence students' engagement and learning outcomes in the field of biotechnology (Sundar & Noseworthy, 2016). Students with positive attitudes are more inclined to explore and understand biotech concepts, while negative attitudes may hinder comprehension or lead to disengagement from the subject matter.

Effective educational strategies are crucial for fostering positive attitudes and deepening students' understanding of biotechnology products (Lusk & Rozan, 2018). Transparent communication about the benefits, safety, and ethical considerations of biotech products can cultivate trust and alleviate concerns, thereby increasing student acceptance and engagement with biotechnology concepts.

Therefore, recognizing the impact of attitudes towards biotechnology products on students' learning experiences is essential for Teachers; and hence understanding these

attitudes and tailoring educational approaches accordingly, teachers can enhance students' performance in Biology and cultivate a greater appreciation for biotechnology among learners.

2.7 Biotechnology Acceptance Based on Ethical Considerations

Biotechnology acceptance is intricately linked to ethical considerations, with individuals' attitudes toward these ethical dimensions playing a significant role in shaping acceptance levels.

Ethical considerations in biotechnology encompass a range of issues, including but not limited to, safety, equity, environmental impact, and respect for autonomy (Gaskell et al., 2017). Ethical frameworks such as utilitarianism, deontology, and virtue ethics guide evaluating the moral implications of biotechnological innovations.

Individuals' attitudes toward the ethical dimensions of biotechnology influence their acceptance of biotechnological products and practices (Siegrist et al., 2019). Positive attitudes toward ethical considerations, such as transparency, accountability, and respect for human rights, are associated with greater acceptance of biotechnology, while concerns about ethical lapses or violations may lead to skepticism or resistance.

Several factors influence attitudes toward the ethical dimensions of biotechnology, including personal values, cultural norms, and trust in regulatory institutions (Habermas, 2018). Media portrayal, public discourse, and educational initiatives also play significant roles in shaping public perceptions and attitudes toward biotechnological ethics.

Attitudes toward the ethical dimensions of biotechnology have a direct impact on acceptance levels within society (O'Riordan & Fotopoulou, 2019). Ethical concerns

raised by stakeholders can lead to public debates, and regulatory scrutiny, and ultimately influence the adoption or rejection of biotechnological innovations.

Ethical considerations are central to biotechnology acceptance, with attitudes toward these dimensions playing a pivotal role in shaping public perceptions and decision-making. By addressing ethical concerns transparently, promoting accountability, and engaging stakeholders in dialogue, the biotechnology community can foster greater acceptance and trust in the responsible development and application of biotechnological innovations.

2.8 Acceptance and rejection based on environmental impacts

The acceptance and rejection of biotechnology are often influenced by perceptions of its environmental impacts. Biotechnological applications can have various environmental impacts, including changes to ecosystems, biodiversity, and the introduction of genetically modified organisms (GMOs) into the environment (Pardo, Calvo, & Gomez, 2019). Positive environmental impacts, such as reduced pesticide use and increased crop yields, may enhance acceptance, while concerns about unintended consequences or ecological disruption may lead to rejection.

Individuals' attitudes toward the environmental impacts of biotechnology play a significant role in shaping their acceptance or rejection of biotechnological innovations (Kellner, 2018). Positive attitudes toward environmental stewardship and sustainability are associated with greater acceptance, whereas concerns about ecosystem integrity, biodiversity loss, and the spread of genetically modified organisms may lead to rejection.

Factors that influence attitudes toward the environmental impacts of biotechnology, includes scientific literacy, trust in regulatory agencies, and media coverage (Brossard

& Nisbet, 2007). Personal values, cultural norms, and socio-economic factors also shape individuals' perceptions of environmental risks and benefits associated with biotechnological innovations.

Attitudes toward the environmental impacts of biotechnology directly impact acceptance levels within society (Marris, Joly, & Heraud, 2001). Public concerns about environmental risks can lead to opposition to biotechnological applications, regulatory scrutiny, and resistance from environmental advocacy groups, ultimately influencing policy decisions and market acceptance.

Attitudes toward the environmental impacts of biotechnology play a crucial role in shaping public acceptance or rejection of biotechnological innovations. By addressing environmental concerns transparently, engaging stakeholders in dialogue, and promoting sustainable practices, the biotechnology community can foster greater acceptance and trust in the responsible development and application of biotechnological innovations.

2.9 Acceptance of Biotechnology Applications in the Medical Field

The acceptance of biotechnology applications in the medical field is influenced by individuals' attitudes toward these innovations and hence understanding the relationship between attitudes and acceptance is crucial for realizing the potential benefits of biotechnological advancements in healthcare.

Biotechnology has revolutionized medicine by enabling advancements such as precision medicine, gene therapy, and biopharmaceuticals. These applications hold promise for improved diagnostics, treatments, and personalized healthcare solutions, but their acceptance hinges on the public especially students' attitudes toward their safety, efficacy, and ethical implications.

Attitudes toward medical biotechnology encompass perceptions of its benefits, risks, and ethical considerations (Macer, 2016). Positive attitudes are often associated with optimism about the potential to cure diseases, enhance patient outcomes, and improve quality of life. Conversely, concerns about safety, privacy, and equity may lead to scepticism or resistance.

Numerous factors influence the acceptance of biotechnology applications in medicine, including trust in healthcare professionals, regulatory agencies, and pharmaceutical companies. Knowledge levels, prior experiences with healthcare interventions, and cultural beliefs also shape individuals' perceptions and attitudes toward medical biotechnology.

Positive attitudes may encourage patient engagement and adoption of innovative therapies, whereas negative attitudes can hinder acceptance and uptake, limiting access to potentially life-saving treatments.

Attitudes toward biotechnology applications in the medical field significantly influence their acceptance and adoption within society. By addressing public concerns, fostering trust, and promoting education about the benefits and risks of medical biotechnology, stakeholders can enhance acceptance and facilitate the responsible integration of biotechnological innovations into healthcare practices which also leads nurturing of more personnel in the field

2.10 Perceptions of Biotechnology

Students' perceptions of biotechnology significantly influence their engagement and motivation in learning. According to Koballa and Glynn (2007), perception refers to students' subjective interpretations and evaluations of biotechnological concepts, applications, and ethical considerations. Positive perceptions of biotechnology can

foster curiosity, interest, and enthusiasm for learning, while negative perceptions may lead to disengagement and reluctance to explore biotechnological topics.

People often interpret the same situation differently, leading them to form different attitudes (Bahri, Surwayati, & Osman, 2014). Developing a positive attitude depends on having a positive perception, since a sound perception enables individuals to evaluate issues more critically and rationally, without being clouded by emotions. Studies have shown a strong positive relationship between perception and attitude, for example, in relation to the preservation of information resources (Oyeniyi, 2009). Similarly, people's perceptions of technological features can influence and even predict their attitude toward the use of technology and their actual behaviour. This study also draws on the work of Dawson and Venville (2009), who noted that while there is extensive research on public knowledge, perceptions, and attitudes toward biotechnology in developed nations (Dawson & Venville, 2009; Klop & Severiens, 2007; France, 2003; Rota & Izquierdo, 2003), there is still a lack of research in developing countries such as Ghana, particularly at the school level. In Malaysia, research on this issue is still very limited, and no study has yet been conducted that specifically measures students' literacy in biotechnology (Bahri et al., 2014). This study focuses on senior high school students for several reasons. As explained by Bahri et al. (2014), secondary school students are considered the most suitable group to build foundational knowledge, shape perceptions, and develop attitudes toward biotechnology, since they represent the future generation that will help drive Malaysia's progress into a high-income and developed nation by 2020. This aim is consistent with the government's recognition of the biotechnology sector as one of the five key industries essential for achieving that vision (RMK9, 2006, cited in Bahri et al., 2014).

Teachers can shape students' perceptions of biotechnology by highlighting its potential benefits, ethical considerations, and real-world applications (Koballa Jr. & Glynn, 2007). By contextualizing biotechnological concepts within relevant societal issues, such as food security, healthcare, and environmental sustainability, teachers can demonstrate the relevance and importance of biotechnology in addressing global challenges. Additionally, discussions on ethical principles and responsible use of biotechnology promote ethical awareness and encourage students to consider the ethical implications of biotechnological advancements (Koballa Jr. & Glynn, 2007).

2.11 Perceived risks and benefits of biotechnology

Biotechnology has revolutionized various aspects of human life, including medicine, agriculture, and environmental science. However, the rapid advancement of biotechnology has also raised concerns about its potential risks and benefits. This literature review aims to explore the perceived risks and benefits of biotechnology.

Research has shown that the public perceives several benefits of biotechnology, including improved health outcomes, increased food production, and environmental sustainability (Gaskell, Allum & Stares, 2003; Pardo & Calvo, 2008). For instance, a study found that genetically modified crops can increase crop yields and reduce pesticide use, thereby benefiting farmers and the environment (Klumper & Qaim, 2014).

Despite the perceived benefits, biotechnology also raises concerns about potential risks, including unintended environmental consequences, health risks, and ethical concerns (Kuzma & Kokotovich, 2017; Sleight & Evers, 2014). For example, a study found that genetically modified organisms (GMOs) can potentially harm non-target species and contaminate non-GMO crops (Snow, 2002).

Public perception of biotechnology is influenced by various factors, including media coverage, public debates, and trust in regulatory agencies (Gaskell et al., 2003; Pardo & Calvo, 2008). A study found that public trust in biotechnology is higher in countries with strong regulatory frameworks and transparent decision-making processes (Pardo & Calvo, 2008).

The perceived risks and benefits of biotechnology are complex and multifaceted. While biotechnology offers several benefits, including improved health outcomes and environmental sustainability, it also raises concerns about potential risks, including unintended environmental consequences and health risks. Understanding public perception of biotechnology is crucial for developing effective regulatory frameworks and promoting public trust in biotechnology.

2.12 Perception Towards Ethics in Biotechnology

In recent years, the intersection of biotechnology and ethics has garnered significant attention due to its implications for human health, the environment, and society at large. Biotechnological advancements, such as gene editing and genetically modified organisms (GMOs), have raised complex ethical questions regarding their safety, environmental impact, and socio-economic implications (Gaskell et al., 2017). Scholars have proposed various ethical frameworks to address these concerns, including utilitarianism, deontology, and virtue ethics, each offering distinct perspectives on how to evaluate the ethical implications of biotechnological innovations.

Public perception plays a pivotal role in shaping the ethical discourse surrounding biotechnology. Studies have indicated that public attitudes towards biotechnological applications are often influenced by factors such as trust in scientific institutions, religious beliefs, and perceived risks and benefits (Siegrist et al., 2019). Moreover,

media portrayal and public engagement initiatives have been shown to impact public perceptions of biotechnological ethics (Bubela et al., 2018).

Regulatory frameworks and policy decisions also play a crucial role in shaping the ethical landscape of biotechnology. Government agencies, such as the Food and Drug Administration (FDA) in the United States so as Ghana, are tasked with evaluating the safety and ethical implications of biotechnological products before they are introduced to the market (Kuzma & Kokotovich, 2017). However, navigating the regulatory landscape can be challenging, particularly in rapidly evolving fields such as gene editing and synthetic biology.

As biotechnology continues to advance, it is imperative to foster ongoing dialogue and collaboration among stakeholders to ensure that ethical considerations remain at the forefront of decision-making processes. This includes promoting transparency, accountability, and public engagement initiatives to address concerns surrounding biotechnological ethics (O’Riordan & Fotopoulou, 2019). Additionally, interdisciplinary research efforts that integrate perspectives from ethics, law, and the social sciences will be essential for navigating the complex ethical challenges posed by emerging biotechnologies.

In conclusion, perceptions towards ethics in biotechnology are multifaceted and influenced by a variety of factors, including societal values, regulatory frameworks, and public engagement efforts. By fostering open dialogue and interdisciplinary collaboration, stakeholders can work towards ensuring that biotechnological advancements are developed and implemented in a manner that upholds ethical principles and promotes the well-being of society as a whole.

2.13 Perception of Religious and Moral Perspectives in Biotechnology

Biotechnology has revolutionized various aspects of human life, including medicine, agriculture, and environmental science. However, the rapid advancement of biotechnology has also raised ethical concerns, particularly with regards to religious and moral perspectives.

Research has shown that religious beliefs play a significant role in shaping public attitudes towards biotechnology (Carter & Gruen, 2018). For instance, a study found that religious individuals were more likely to oppose genetic engineering and stem cell research due to concerns about the sanctity of human life (Evans, 2010). Similarly, another study revealed that Muslim and Christian communities had differing views on biotechnology (Sleigh & Evers, 2014).

Moral perspectives on biotechnology are also varied and complex. Some argue that biotechnology has the potential to alleviate human suffering and improve quality of life, thereby aligning with moral principles of beneficence and non-maleficence (Habermas, 2003). Others, however, raise concerns about the potential risks and unintended consequences of biotechnology, such as genetic modification and cloning (Kass, 2002).

Public perception of biotechnology is influenced by a range of factors, including religious and moral perspectives. A study found that public attitudes towards biotechnology were often shaped by media coverage and public debates, which frequently framed biotechnology in terms of moral and ethical concerns (Gaskell et al., 2003). Another study revealed that public trust in biotechnology was influenced by perceptions of scientific expertise and regulatory oversight, as well as moral and ethical considerations (Pardo & Calvo, 2008).

The perception of religious and moral perspectives in biotechnology is complex and multifaceted. Research highlights the importance of considering these perspectives in public debates and policy-making surrounding biotechnology. By engaging with diverse religious and moral perspectives, we can foster a more nuanced understanding of the ethical implications of biotechnology and promote more informed decision-making.

2.14 Literacy in Biotechnology

Several scholars have provided different definitions to describe scientific literacy. Miller (2007), for instance, described it as the level of science and technological knowledge that citizens need to be effective members of a modern industrialized society. Murcia (2007) described scientific literacy as a broad and functional understanding of science, either individually or communally, that enables effectiveness and encourages the use of scientific knowledge in addressing personal and societal needs. Similarly, Bybee (2008) viewed scientific literacy as not just the learning of scientific knowledge, but also the ability to apply the knowledge to formulate scientific questions, explain scientific phenomena, and make evidence-based decisions on issues that relate to science. His definition also included determining the big characteristics of science as a human endeavor, appreciating how science and technology affect cultural, material, and intellectual environments, and having a disposition to participate in discussion on matters of science. At the community level, scientific literacy is conceived as a necessity for understanding and communicating scientific ideas. Cumulatively, these perspectives state that scientific literacy is the ability to utilize knowledge of basic science to reason logically about everyday problems, inform attitudes through enlightened insights, and guide decisions and actions based on scientific information (Bahri et al., 2014).

Literacy forms the foundation of effective learning in biotechnology education. According to Bakanauskas et al. (2020), literacy encompasses not only reading and writing skills but also the ability to comprehend and critically analyze scientific information. In the context of biotechnology, literacy involves understanding complex scientific concepts, interpreting data, and evaluating the implications of biotechnological advancements. Therefore, Teachers must employ various instructional strategies to cater to students' diverse literacy levels.

Interactive discussions, as suggested by Bakanauskas et al. (2020), allow students to engage with biotechnological concepts through dialogue and debate, promoting active learning and critical thinking. Additionally, hands-on activities, such as laboratory experiments and practical demonstrations, provide students with tangible experiences that reinforce theoretical knowledge and enhance comprehension. By incorporating visual aids, multimedia presentations, and real-life examples, Teachers can make biotechnology more accessible and comprehensible to students with varying literacy levels.

Research on gender differences in biotechnology literacy levels among senior high school biology students reveals mixed findings. This review aims to explore the relationship between gender and biotechnology literacy levels. Studies suggest that gender differences in biotechnology literacy levels are nuanced.

A study by Hill, Corbett & St. Rose (2010) found that male students tend to perform slightly better in science and technology subjects, including biotechnology. On the hand, Mwangi & Mwangi (2015), suggests that with effective teaching approaches, there are no significant differences in biotechnology literacy levels between male and female students.

The relationship between gender and biotechnology literacy levels is complex and influenced by various factors. Further research is needed to understand the nuances of this relationship and to develop effective strategies for promoting biotechnology literacy among all students.

2.15 Elements in scientific literacy

To determine the presence of scientific literacy in a community, its primary elements should first be identified. Previous literature has outlined several dimensions of scientific literacy. Miller's (1983) early work, for example, not only offered a multidimensional definition but also practical approaches to measuring scientific literacy. His model, widely accepted and used in subsequent research, defines science-literate persons as those who are acquainted with the science ways and sciences (nature of science), have information about basic scientific ideas and vocabulary, and understand the role of science and technology in society. Later, in 1989, the American Association for the Advancement of Science (AAAS) in its reform initiative, Project 2061, broadened the scientific literacy definition to include "habits of mind." According to AAAS (1989), being scientifically literate is to understand the interconnectedness of the natural world, comprehend the mathematics-technology-science interdependence, and understand essential scientific concepts and principles.

In addition, elements of science literacy also include:

- i) capacity for scientific ways of thinking.
- ii) knowledge of science, mathematics, and technology are human enterprises, and
- iii) knowing the implications of their strengths and limitations.
- iv) being able to use scientific knowledge and creative ways of thinking for personal and social purposes.

Laugksch and Spargo (1996) highlighted that scientific literacy goes beyond just having knowledge in science, technology, and mathematics; it also includes the values, attitudes, and ways of thinking that come with those areas. In line with this, the OECD (2006), through its PISA framework, described scientific literacy as involving several key aspects. These include being able to use scientific knowledge to ask questions, gain new insights, explain natural or technical processes, and base conclusions on evidence. It also involves understanding how science works as a form of human inquiry, recognizing the influence of science and technology on society and culture, and having an informed attitude towards science-related issues as a responsible member of the community.

In a study discussed by Bahri et al. (2014), Klop and colleagues (2010) looked at how students' knowledge and perceptions influence their attitudes toward biotechnology. Their work suggests that scientific literacy can be understood through the way knowledge and perception shape attitudes. However, scientific literacy should not be seen as a single fixed skill. Bybee (2008) explained that it can be developed at different levels. At the most basic level, called the nominal stage, a person may recognize scientific words but not really know what they mean. The functional stage goes a bit further, where individuals can use scientific terms correctly but only in limited situations. A more advanced level involves understanding how concepts and processes connect, showing both comprehension and application. The highest level, which Bybee called multidimensional, includes not just understanding science but also being able to view its role in personal and social contexts.

Similarly, the PISA framework (2006, cited in Bahri et al., 2014) stresses that scientific literacy is better seen along a spectrum rather than as a simple divide between literate and illiterate. In this view, people may fall at different points either low, medium, or high depending on how well they can apply scientific ideas in real-world contexts.

Scientific literacy is important because it helps people think critically, evaluate issues, and make informed choices about matters that are ethical, social, political, and economic (France, 2003). In this context, biotechnology education is especially relevant. Teaching students about biotechnology at an early stage not only equips them with the knowledge to be scientifically literate but also prepares some of them to become future scientists in the field (Bahri et al., 2014).

In today's globalized world, young people are exposed to a wide range of biotechnology-related issues and applications, often similar to what adults encounter. However, without clear and proper teaching, they may struggle to understand these issues, leading to misconceptions and negative attitudes (Bahri et al., 2014; Rota & Izquierdo, 2003). Since students will eventually become the next generation of decision-makers, it is vital that they are guided to build a balanced view of biotechnology and its role in society (Bahri et al., 2014).

For Malaysia, this means strengthening biotechnology education through effective teaching methods and curriculum design. Doing so will not only help the population appreciate the benefits of biotechnology for economic growth, but also highlight its potential in addressing future global challenges such as population growth, food and water security, climate change, and economic or political instability (Bahri et al., 2014). Considering the rapid population growth, increased need for food and water as well as

increased release of pollutants in Ghana, our students who are our future leaders need to be abreast with biotechnology content in biology.

This study aims to investigate students' literacy perception and attitude towards biotechnology based on the Ghanaian syllabus among school students. Building on earlier studies, this research draws on key components of scientific literacy, specifically knowledge, perception, and attitude to evaluate how scientifically literate school students are. For this purpose, Bybee's framework of scientific literacy levels was adapted. In this study, scientific literacy is considered present when there is a positive relationship between students' knowledge and their attitude toward biotechnology, as well as between their perception and their attitude (Bahri et al., 2014).

This view is supported by previous findings. Ibrahim and Babayemi (2010) suggested that knowledge is a necessary foundation for the development of any attitude. Similarly, Morren, Kok, and van der Laan (2007) found that greater knowledge often corresponds with more favourable attitudes towards biotechnology. At the same time, perception also plays a central role, as attitudes are often shaped by how individuals perceive a subject.

2.16 International Studies on Knowledge and Attitudes Towards Biotechnology

During the early 2000s, researchers like Condit (2010) hinted a rise in studies exploring public understanding of biotechnology and related attitudes. However, interest in this area appeared to dip in the following decade, even as major innovations like the development of CRISPR/Cas9 reignited the need to reexamine public perceptions (Doudna & Charpentier, 2012).

In fact, much of the data on European public attitudes toward biotechnology comes from the Eurobarometer 2010 survey, which measured changes in perception across countries (European Commission, 2010). For example, around half of Europeans were optimistic about biotech, though acceptance varied widely between nations, such as between Sweden and Spain.

Regional differences were particularly interesting: Swedish respondents often raised ethical concerns about genetically modified foods concerns not easily outweighed by practical benefits like improved taste or lower price. Still, when potential advantages for health or the environment were emphasized, willingness to purchase products increased.

Synthesizing these findings emphasizes the importance of using consistent tools to compare attitudes across contexts. In our study, we similarly compared biotechnology literacy and perceptions among Swedish and Spanish pre-service primary school teachers. This dual-sample comparison from northern and southern Europe helps us better understand how cultural context affects future educators' readiness to teach biotech topics.

2.17 Relationship Among Literacy, Perception, and Attitude in Biotechnology

Literacy, perception, and attitude are interconnected factors that influence public understanding and acceptance of biotechnology. Research has shown that individuals with higher literacy levels tend to have more positive attitudes towards biotechnology (Brossard & Nisbet, 2007) Conversely, those with lower literacy levels may hold more negative perceptions due to a lack of understanding (Priest, 2001).

Perception plays a crucial role in shaping attitudes towards biotechnology, with factors like risk perception, benefit perception, and trust influencing public opinion (Siegrist,

2000). Literacy levels can impact perception, as individuals with higher literacy may be better equipped to critically evaluate information and make informed decisions (Kahan, 2010).

Attitudes towards biotechnology are also influenced by factors like religiosity, worldviews, and personal values (Brossard, Scheufele, Kim, & Lewenstein, 2009). However, literacy can moderate the relationship between these factors and attitude, as individuals with higher literacy may be more open to diverse perspectives (Nisbet & Goidel, 2007).

Education and media literacy programs can enhance literacy and critical thinking skills, leading to more informed attitudes towards biotechnology (Miller, 2004). Effective communication strategies can also promote positive attitudes by addressing public concerns and increasing trust (Frewer & Shepherd, 1998).

The integration of literacy, perception, and attitudes in teaching biotechnology is crucial for fostering a comprehensive understanding and positive engagement with the subject matter. By employing diverse teaching strategies and creating a supportive learning environment, Teachers can effectively address students' varying literacy levels, shape their perceptions of biotechnology, and cultivate informed attitudes grounded in critical thinking and real-world application.

The integration of literacy, perception, and attitudes in teaching biotechnology is also essential for nurturing informed and engaged learners, therefore, employing diverse teaching strategies, fostering a positive perception of biotechnology, promoting critical thinking and reflection, and providing hands-on learning opportunities; can empower students to become competent and responsible participants in the dynamic field of biotechnology.

2.18 Biotechnology Education

When students learn about biotechnology in Science or Biology classes, they are introduced to a field that is both old and new. On the one hand, biotechnology includes traditional practices such as making bread or wine. On the other hand, it also covers modern developments like genetic engineering, which open up new opportunities but also bring ethical questions. Because of this mix of promise and controversy, schools have an important role to play. Teachers need to provide students with clear scientific knowledge while also preparing them to think critically about the benefits and risks of biotechnology as future decision-makers.

From an educational point of view, teaching should cover both the basic principles of biotechnology and its broader effects on society. The aim is to help students understand key methods, achievements, and impacts, while also guiding them to form their own well-reasoned opinions. Since the life sciences have expanded so rapidly in recent decades, teachers need to focus on the main application areas such as medicine, pharmaceuticals, agriculture, food production, and environmental technology as well as important techniques like genetic engineering, cell culture, and the use of microorganisms.

Among these, genetic engineering is one of the most widely discussed areas because of its potential for the future. This makes it especially useful as a teaching example. Microorganisms, particularly bacteria, play a central role in many biotechnological processes, so understanding them is key. Research also shows that students' existing ideas strongly influence how well they learn. For example, studies on misconceptions about bacteria highlight the need to address prior knowledge when teaching biotechnology. Motivation is another important factor, students learn better when they

are genuinely interested in the topic. Research on student interest in gene technology confirms this link.

Because biotechnology is a complex subject that touches many areas of life, it should ideally be taught in an interdisciplinary way. This approach, supported with well-designed teaching materials, can make learning about biotechnology more engaging and meaningful.

According to Bahri et al. (2014), education plays a central role in a country's development because it provides the skilled professionals and technical experts needed in different fields. Education also shapes people's attitudes and values, helping them to accept change, embrace innovation, and apply science and technology both at work and in everyday life. Kolarova (2014) points out that public opinion about biotechnology is often divided—it brings hope for solving major global issues, but at the same time, it raises a lot of concerns. For example, genetic engineering is seen as a way to improve human health, reduce hunger worldwide, and find sustainable solutions for managing natural resources. However, it also creates social, moral, cultural, economic, and religious debates that are constantly discussed in the media and society.

Some of the most controversial areas include the possible risks of genetically modified foods and transgenic plants on human health and the environment (Coghlan et al., 2002), questions about whether altering the genes of living organisms is morally acceptable, the fairness and safety of using gene therapy in medicine (Marshall, 2000), and the ethical standards surrounding the sharing of human genome information (McInerney, 1996). In Ghana, both traditional and modern biotechnology practices are widely used, but there are still doubts about how acceptable biotechnology really is.

Science education, especially biology, is considered very important in helping students understand and respond to these challenges (Osborne, Simon, & Collins, 2003). Schools are expected to prepare young people to become responsible citizens who can make informed choices about biotechnology (Kolarova, 2014). To do this, it's not enough for students to just know the science; they also need to be aware of the possible social and moral consequences. This way, they can learn to weigh both the advantages and the risks of biotechnology (Kolarova, 2014).

Research has shown that the knowledge and opinions students form about genetic engineering during school can help them later in life as citizens and professionals when they need to make careful and ethical decisions. Science classrooms also provide a space where teenagers can practice making reasoned judgments about biotechnology, which can prepare them to take part in future debates and make responsible choices about controversial issues in society. Teenagers themselves are important in this discussion, since they are upcoming consumers with growing independence, unique preferences, and spending power (Kolarova, 2014). For this reason, Bahri et al. (2014) argue that biotechnology education should start early to raise students' awareness and give them a better understanding of these issues.

Secondary school students need more exposure and education in biotechnology because of how complex the field is. It not only involves advanced technical knowledge (France, 2003; Wells & Kwon, 2008), but it also comes with social, political, and ethical issues that require critical thinking to properly understand (France, 2003). Teenagers, especially students, are also important because they represent the next generation of consumers. The values, opinions, and habits they form during adolescence can strongly influence their choices and consumer behaviour in the future.

Kolarova (2014) notes that most of the existing research on modern biotechnology focuses on it as a sociological subject. Researchers are usually interested in people's level of awareness, how much they understand biotechnology, and their attitudes towards its different applications in areas like medicine, pharmacology, agriculture, food production, and environmental protection. In Ghana, however, there is still very little knowledge or research on biotechnology education, both in its traditional and modern forms, which means its full importance has not yet been recognized.

Kolarova (2014) also explained that many public opinion surveys on biotechnology have been carried out, mostly among adults in different regions such as the European Union (Gaskell, Allum, & Staes, 2003), the United States (Moon & Balasubramanian, 2004), Australia (Eureka Strategic Research, 2007), and Japan. Findings show, for example, that Europeans are generally more supportive of biotechnology when it is applied in medicine like organ transplants or genetic testing than when it is used in agriculture and food production (European Commission, 2001).

Despite these surveys, Kolarova (2014) highlights that there is still limited research on what school-age students know and think about modern biotechnology. The few studies that exist can generally be grouped into three main categories:

1. Studies that focus on the cognitive processes and their results – mainly the content knowledge and understanding of modern biotechnology.
2. Studies that focus on the affective processes and their products – most often the students' attitude expressed in the form of assessment (approval/disapproval) to different aspects of biotechnology.
3. Studies in which science Teachers examine the relationship between high school students' understanding and attitude to genetic engineering.

Research on students' knowledge of modern biotechnology shows similar patterns across different studies as most high school students have limited understanding of the processes and recent developments in the field, and many are only able to give a few examples, sometimes even incorrect ones (Kolarova, 2014). For instance, Lock and Miles (1993) reported that 52% of 188 British students aged 14–16 could not name a single example of genetic engineering. Likewise, a study in Australia found that around 20–30% of 1,116 students (aged 15–16) could not provide examples of applications like gene engineering, cloning, or genetically modified foods, and many were confused about the difference between transgenic foods and those produced through selective breeding (Dawson & Soames, 2006).

One reason for this gap is that there has been relatively little research focused on high school students' knowledge and attitudes towards biotechnology. Most surveys tend to look at adult consumers' views of genetic engineering, rather than those of younger students (Kolarova, 2014). In the context of secondary biology education, only a small number of studies have explored students' knowledge and attitudes empirically, and even fewer have investigated the relationship between knowledge and attitudes or examined students' opinions about gene technology through experiments (Kolarova, 2014).

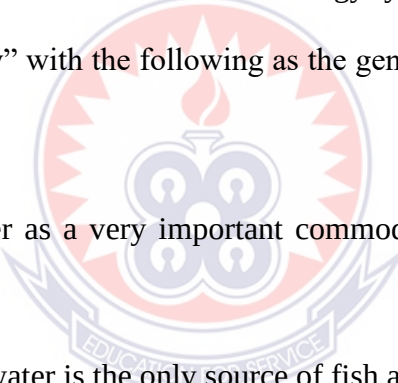
The PISA science survey is worth mentioning here, as it assessed students' general knowledge of science along with their attitudes towards science, technology, and specific issues such as the environment (OECD, 2009). While more international studies are beginning to examine how students understand and feel about modern biotechnology, Bulgaria is still only starting to develop research in this area (Kolarova, 2014). The literature shows that very little has been published, with some studies focusing on biotechnology training programs and challenges in teaching the subject

(Alexieva & Dimkov, 2007), and only a few looking at how older students (17–18 years) view the social and ethical issues linked to genetic engineering.

This research represents part of a larger investigation of biology students' literacy levels, perceptions of, and attitudes toward biotechnology. This study was focused on the processes, applications, and products of both traditional and modern biotechnology.

2.19 Biotechnology Education in Ghanaian Senior High Schools

Biotechnology is a fascinating and rapidly developing field that has important implications for the future of agriculture, medicine, and industry. As such, it is a valuable topic included in the Senior High School biology syllabus in Ghana. Biotechnology is a unit under section 4 of the biology syllabus. The theme of the section is “biology and industry” with the following as the general objectives in the Ghanaian context:

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- i) Appreciate water as a very important commodity that must be handled with care;
 - ii) appreciate that water is the only source of fish and useful aquatic products.
 - iii) It is a medium for the transmission of some diseases;
 - iv) understand that water is the basic raw material for industries;
 - v) appreciate the use of micro-organisms in industries and
 - vi) be aware that fuel can be generated from biological sources

Subdivision (units) of the section are:

- Unit 1: Biology and Water Industry
- Unit 2: Biology and Fishing industry
- Unit 3: Biology and Food industry
- Unit 4: Biology and Agriculture

- Unit 5: Biotechnology
- Unit 6: Biological Fuel Generation

This study focused on unit 5, biotechnology, even though the entire section is primarily centered on biotechnology. The students are expected to explain the concept of biotechnology and then investigate processes involving the use of microorganisms in the manufacture of cheese, yoghurt, kenkey, bread, and butter. They also investigate the processes in micro-organisms and liquor production, micro-organisms in the pharmaceutical industry, mining industry, and tanning industry. Other concepts such as cell biology and genetics which are foundations for this concept are also enshrined in the syllabus. It concluded that if students are exposed to this life-sustaining concept, they will contribute to the development of the country but on the contrary biology students are even unaware of the concept which is the backbone of biotechnology education in Ghana.

2.20 Applications of Biotechnology

The word biotechnology was first introduced in 1917 by a Hungarian engineer named Karl Ereky, who described it as the process of producing goods with the help of living organisms (Lamanauska, 2008). Biotechnology involves techniques that make use of living systems to create products, especially in sectors like medicine, agriculture, and industry, with the aim of improving human health, protecting the environment, and enhancing plant and animal production (Eroglu, 2006).

Today, biotechnology can be seen in many areas of life such as healthcare, food production, and farming. At its core, it is a technology that relies on living organisms, biological products, and genetic engineering methods to create benefits for society (Darcin, 2007). In simple terms, biotechnology is the use of biology to solve problems

and develop useful products. One of its most notable applications is the production of therapeutic proteins and medicines through genetic engineering.

Overall, biotechnology can be defined as the use of biological systems and organisms to design or produce valuable products and address challenges. It is a multidisciplinary field that brings together knowledge from engineering, chemistry, genetics, and other sciences to create innovative processes and solutions.

According to Bull, Holt, and Lilly (1982), biotechnology is defined as the application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services. In a similar definition by Boyer (2016), it is the technique of using live organisms or enzymes from organisms to produce products and processes useful to humans. According to Adeogun (2018), from the foregoing, one could think of making wine using microbe-based processes as a form of biotechnology; however, biotechnology is used in a restricted sense to refer to the use of genetically modified organisms to produce products and processes for mankind.

2.21.1 Applications of biotechnology across the globe

The Open Forum on Agricultural Biotechnology (OFAB) is an open discussion forum with six Chapters in Africa, including Kenya, Uganda, Tanzania, Nigeria, Ghana, and Burkina Faso (Nordqvist & Johansson, 2019).

OFAB – Ghana is a platform that brought together all stakeholders in Biotechnology to interact and discuss biotechnology to bring awareness of the technology and provide correct information to all stakeholders including scientists, journalists, and media personnel, farmers, consumers, students from secondary and tertiary institutions, agriculture extension officers, traditional rulers, civil society, and policymakers. Local

languages are used during discussions for better understanding of issues (Nordqvist & Johansson, 2019).

According to Nordqvist and Johansson (2019), the vision of the OFAB Ghana Chapter is to build an informed and interactive society that can make sound decisions about agricultural biotechnology research, regulation, development, and commercialization. Its mission is to create opportunities for dialogue and international collaboration among stakeholders through constructive discussions and networking.

Their activities have helped improve the understanding of biotechnology among the media and consumer groups. For example, accurate information on GMOs is now more widely shared, outreach programs have reached broader audiences, and study tours have exposed farmers and scientists to biotechnology facilities and farms, including visits to Bt-Cotton fields in Burkina Faso.

The OFAB Ghana Chapter focuses on ensuring food security and empowering farmers by encouraging self-sufficiency in crop and livestock production rather than relying on foreign aid (Nordqvist & Johansson, 2019). It also stresses the importance of sharing correct information about biotechnology, making biotech trials transparent, and releasing safe products. Crops like maize, soya beans, cotton, tomatoes, and papaya, as well as animals such as sheep, cattle, and poultry, are among the key targets for biotechnology. Apart from agriculture, biotechnology also contributes to health in the form of vaccines and drugs such as insulin and smallpox vaccines, and industry in decontaminating oil spills and organic waste conversion.

Biotechnology, in short, uses scientific methods to design genetically modified plants that are more resistant to insects, disease, and drought, and mature earlier (Nordqvist & Johansson, 2019). Ghana's Biosafety Act of 2011 passed by President Evans Atta Mills

is the law for this. CSIR, University of Ghana, KNUST, BNARI at the Ghana Atomic Energy Commission, and CRIG are leading in biotechnology research. They use molecular breeding, conventional breeding, plant pathology, and tissue culture in their activities.

Ghanaian modern biotechnology is mainly applied in agriculture, medicine, and industry. In agriculture, it is employed to enhance the yield and resistance of crops to diseases, weeds, and insects, and in medicine to generate vaccines and hormones, and in industry to fight the threat of oil spillage. Among the major challenges farmers face is post-harvest loss of fruits such as tomatoes and papayas that are fragile. Technologies like delayed ripening, already available in countries like the US, Canada, Mexico, and certain regions of Asia, enhance shelf life and reduce wastage.

Tissue culture is another important area of biotechnology where portions of plants are sterilized, grown on a nutrient agar, and induced into plantlets before they are transplanted into soil. This is applied to fruits like banana, plantain, and pineapple. Modern techniques also allow for the selection of useful genes to improve drought resistance, herbicide tolerance, pest resistance (e.g., Bt cotton and maize), and nutritional value, as seen in Golden Rice, which has been fortified with vitamin A to combat blindness in children caused by vitamin A deficiency (Nordqvist & Johansson, 2019).

Weeds, which reduce crop yield and quality while spreading pests and blocking irrigation, can be managed through biotechnology by developing herbicide-tolerant plants. This reduces the need for repeated spraying and promotes environmentally friendly farming. Similarly, Bt technology, which introduces a bacterium (*Bacillus thuringiensis*) into crops, enables the plant to produce proteins that kill pests like cotton

bollworm and corn borers. Biotechnology has also advanced micronutrient fortification of cereals through genetic engineering, such as the insertion of foreign genes into rice to produce beta-carotene, leading to crops like Golden Rice enriched with vitamin A (Nordqvist & Johansson, 2019).

Genetically Modified Organisms (GMOs) come with many advantages, including higher crop yields when weeds and pests are effectively controlled. This helps farmers cut down on costs such as hiring extra labor and buying insecticides, which in turn increases their profits and improves their health by reducing exposure to harmful chemicals (Nordqvist & Johansson, 2019). Another benefit is the development of drought-tolerant crops that can help reduce the impact of climate change, particularly in areas that are prone to drought (Nordqvist & Johansson, 2019).

Despite these benefits, there are also concerns about GMOs. Possible risks include the introduction of allergens and harmful compounds into food, the transfer of transgenes to wild plant relatives, pests eventually becoming resistant to toxins produced by GM crops, and unintended effects on non-target organisms, which could disturb ecosystems. Other concerns involve the creation of “superweeds” resistant to herbicides, as well as social, cultural, and ethical issues such as farmers becoming dependent on multinational seed companies and small-scale farmers being forced out of business (Nordqvist & Johansson, 2019).

Currently, the largest GMO-producing countries, measured in millions of hectares, include the USA, Brazil, Argentina, India, China, South Africa, Burkina Faso, and Egypt, with crops such as maize, soybeans, cotton, tomatoes, and papaya depending on the country’s focus. In Sub-Saharan Africa, Ghana, Kenya, Nigeria, and Uganda are also actively working on GM crop development (Nordqvist & Johansson, 2019).

Nordqvist and Johansson (2019) report that interest in GMOs has grown significantly. In 2011, about 16.7 million farmers across 29 countries cultivated 160 million hectares (395 million acres) of GM crops—an 8% increase, or 12 million hectares (30 million acres), compared to 2010. By 2012, production levels continued to rise. Despite this growth, GM crops are strictly regulated to safeguard both food and the environment.

One of the key frameworks guiding this regulation is the Cartagena Protocol, adopted on 29th January 2000 and enforced from 11th September 2003. Ghana became a party to it on 30th May 2003. The protocol ensures the safe transfer, handling, and use of living modified organisms (LMOs) that could affect biodiversity, human health, or the environment. It specifically regulates the cross-border movement of LMOs, gives countries the right to decide whether to accept them, and requires that such decisions be shared through the Biosafety Clearing House (Nordqvist & Johansson, 2019).

In Africa, 37 countries have ratified or acceded to the Cartagena Protocol. These include Algeria, Benin, Botswana, Burkina Faso, Cameroon, Cape Verde, Democratic Republic of the Congo, Djibouti, Egypt, Eritrea, Ethiopia, Gambia, Ghana, Kenya, Lesotho, Liberia, Libya, Madagascar, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Seychelles, South Africa, Sudan, Swaziland, Togo, Tunisia, Uganda, Tanzania, Zambia, and Zimbabwe.

Beyond Africa, 33 countries in Asia and the Pacific, 19 in Central and Eastern Europe, 23 in Latin America and the Caribbean, and 20 in Western Europe and other regions have also acceded to the Cartagena Protocol (Nordqvist & Johansson, 2019).

The Biosafety framework for Ghana has put in place a National Biosafety Committee and Technical Advisory Committees; and there is a framework for administrative

guidelines, regulatory systems, risk assessment and management as well as mechanisms for public participation and information dissemination (Nordqvist & Johansson, 2019).

According to Nordqvist and Johansson (2019), in sub-Saharan Africa, there are 200 million chronically undernourished people, 40 million children chronically underweight, and 50 million mostly children suffer from vit. A-deficiency, and 65 % of women of childbearing age are anaemic. The causes have been the result of drought, floods, pests and diseases, poverty, civil wars and displacement; and this provides food for thought that, a boost in agriculture and modern biotechnological activities to increase food production and reduce spoilage drastically to feed the populace with crops like genetically modified maize, soya beans, rice, tomatoes, yam, plantain, and cassava will be the best option to take (Nordqvist & Johansson, 2019).

There are already three trials on GMOs in Ghana. These include two by CSIR-Crops Research Institute on rice and sweet potato, and one trial at CSIR-SARI on Bt-cowpea (Nordqvist & Johansson, 2019).

Nordqvist and Johansson (2019) note that the Millennium Development Goals (MDGs) targeted reducing hunger, poverty, and disease by half by 2015. Specifically, Goals 1, 4, 5, 6, and 7 focused on eradicating extreme hunger and poverty, lowering child mortality, improving maternal health, fighting HIV/AIDS, malaria, and other diseases, and promoting environmental sustainability. In line with these goals, Ghana is encouraged to adopt modern biotechnology to enhance agricultural productivity. For communities such as the Prestea/Huni-Valley Municipality—where mining activities continue to reduce farmland—biotechnology offers an alternative means of survival, especially for students and farmers.

In addition, the Ghana chapter of the Open Forum on Agricultural Biotechnology (OFAB) was launched in August 2011 by Madam Sherry Ayittey, then Minister of Environment, Science, and Technology. The chapter is coordinated by the Director-General of the Council for Scientific and Industrial Research (CSIR), who works in collaboration with the Focal Person, Programming Committees, and Assistants (Nordqvist & Johansson, 2019).

2.21.2 Applications of biotechnology

Biotechnology has wide-ranging applications in fields such as medicine, agriculture, and industry. For example, it plays a role in combining biological data with computer technology (bioinformatics), developing microscopic tools that can operate inside the human body (nanotechnology), and using stem cell research and cloning techniques in regenerative medicine to replace damaged or dead cells and tissues (Adeogun, 2018). Research institutions and companies often bring these areas together, working both at the molecular level and building upward toward pathways, tissues, and organs (Adeogun, 2018).

Beyond healthcare, biotechnology is also valuable in industry, where biological enzymes are used to speed up chemical reactions. It supports environmental cleanup by breaking down pollutants into harmless substances, after which the enzymes naturally die off. In agriculture, genetic engineering is applied to improve crop production (Adeogun, 2018).

2.21.3 Applications of biotechnology in the environment

Environmental biotechnology involves the use of microorganisms to enhance environmental quality. Its main applications include converting organic waste, cleaning up hazardous pollutants, protecting natural resources, and monitoring environmental

conditions (Marian & Violeta, 2013; Gavrilescu, 2010). Adeogun (2018) explains that organic waste such as plants, agricultural residues, and municipal waste can be transformed into valuable bioresources through microbial processes. Since these wastes are largely made up of lignin, cellulose, and hemicellulose, they can be broken down by microorganisms. For instance, cellulolytic bacteria convert cellulose into high-energy food or animal feed, while fungi and other microbes can turn waste into bioenergy products like biofuels (Adeogun, 2018).

Bioremediation, a key aspect of environmental biotechnology, uses biological treatment methods to reduce or remove pollutants from soil, water, air, and waste. Microorganisms including yeasts, fungi, protozoa, rotifers, and bacteria play an important role in this process since many of them can degrade hazardous and persistent chemical pollutants (Gavrilescu, 2010; Adeogun, 2018).

Another important application is environmental protection. For example, biotechnology has been applied to reduce carbon dioxide emissions by capturing CO₂ from industrial discharges or fixing it on-site through bioprocesses involving cyanobacteria (Hitoshi & Nakamura, 2010). This will not only help in mitigating global warming but also allows the captured CO₂ to be converted into biodegradable plastics as alternatives to petroleum-based plastics (Adeogun, 2018).

Finally, environmental monitoring is supported by the use of biosensors in biotechnology. These tools can detect and measure pollutants such as heavy metals, pesticides, herbicides, and organic compounds which will make them useful for tracking pollution levels and ensuring environmental safety (Gavrilescu, 2010; Adeogun, 2018).

2.21.4 Applications of biotechnology in medicine

Adeogun (2018) notes that the primary aim of biotechnology in medicine is to combat and cure diseases. Its applications include the development of drugs and therapeutic products, the use of genetically modified organisms, the analysis of genes associated with genetic disorders, and the correction of genetic defects. Additional areas of medical application are also highlighted by Biotechnonweb (2018) and Mohammad & Narasu (2013, as cited in Adeogun, 2018).

2.21.5 Applications of biotechnology in agriculture

Biotechnology in medicine is largely focused on fighting and curing diseases (Adeogun, 2018). Its applications are wide-ranging and include the production of drugs and therapeutic products, the development of genetically modified organisms for medical use, gene analysis for the detection of genetic disorders, and the correction of genetic defects. Beyond these, other areas of application have also been outlined in studies such as Biotechnonweb (2018) and Mohammad & Narasu (2013, as cited in Adeogun, 2018).

The use of biotechnology in medicine has brought about major advances in healthcare. For example, genetic engineering has enabled the large-scale production of insulin and other essential hormones, while breakthroughs in gene therapy offer hope for correcting inherited disorders. Stem cell research and regenerative medicine also hold promise for replacing damaged tissues and organs.

However, just as in agriculture, the application of biotechnology in medicine raises ethical and safety concerns. Questions are often asked about the long-term effects of genetic modification, cloning, and gene editing, particularly when applied to humans. While many organizations and regulatory bodies have acknowledged the benefits and

approved various medical biotechnologies, there remains ongoing debate about their potential risks.

Over the past few decades, the field has continued to expand, with biotechnology playing a central role in vaccine development, diagnostics, and personalized medicine. Its impact has been most evident in addressing global health challenges, yet its rapid progress calls for careful regulation and ethical consideration.

2.21.6 Applications of biotechnology in food processing

Biotechnology plays an important role in food processing, particularly through fermentation, the use of food additives, and processing aids in food formulations (Adeogun, 2018). Examples of such products include enzymes, amino acids, vitamins, organic acids, certain carbohydrates, and flavouring agents, many of which are produced using genetically modified microorganisms (FAO, 2010, as cited in Adeogun, 2018). Common applications can be seen in the production of cheese, yoghurt, kenkey, bread, butter, and even alcoholic beverages, all of which rely on biotechnological processes.

2.21.7 Application of biotechnology in industry

Industrial biotechnology involves the use of biotechnology for industrial purposes, focusing on the processing of crops and other products for non-food applications (Adeogun, 2018). This includes industrial fermentation and the use of cells, microorganisms, or enzymes to produce valuable products such as chemicals, animal feed, detergents, paper, and bioplastics (Wikipedia, 2018, cited in Adeogun, 2018). By relying on bioprocesses, industrial biotechnology helps reduce dependence on petrochemicals and supports the shift toward a more sustainable economy (Adeogun, 2018). Adeogun (2018) further noted that the revenues of U.S. and European

biotechnology industries nearly doubled between 1996 and 2000, with rapid growth continuing into the 21st century which is driven mainly by innovations in healthcare. By 2020, the global biotechnology market was valued at approximately \$752.88 billion, with further growth expected due to government and industry initiatives aimed at speeding up drug development and product approvals.

2.22 Biotechnological Processes of Biotechnology Products, and Industries Enshrined in the Biology Syllabus

2.22.1 Biotechnological processes in liquor production

Liquor production involves a blend of traditional craftsmanship and modern biotechnological processes. From the fermentation of raw materials to the aging and flavour development stages, biotechnological interventions play a crucial role in shaping the final product.

The selection of raw materials is a critical determinant of liquor quality and character. Grains, fruits, or sugarcane are commonly used as substrates for fermentation, with their composition influencing the flavour profile of the final product. For example, the choice of barley varieties in whiskey production or grape varieties in wine and brandy production can significantly impact the aroma and taste. Biotechnological processes have revolutionized the liquor production industry, enabling the development of new products and improving existing ones (Patel, 2017). One such process is fermentation, which involves the use of microorganisms like yeast and bacteria to convert sugars into alcohol (Ingledew, 2017). Genetic engineering techniques have been used to improve the efficiency and tolerance of these microorganisms, resulting in increased productivity and reduced production costs (Zhang & Liu, 2018).

Another biotechnological process used in liquor production is enzyme-assisted processing, which involves the use of enzymes to break down complex molecules into

simpler ones, improving the flavour and texture of the final product (Arevalo-Villena & Briones-Perez, 2017). For example, enzymes like glucosidase and protease have been used to improve the flavour and clarity of whiskey (Singh & Kumar, 2018).

Biotechnological processes have also been used to develop new products, such as low-calorie and low-alcohol liquors (Liu & Khosla, 2017). For instance, genetic engineering techniques have been used to develop yeast strains that produce fewer calories and less alcohol (Zhang & Liu, 2018).

In addition, biotechnological processes have been used to improve the sustainability of liquor production, such as using biomass-derived feedstocks and the reduction of waste and emissions (Patel, 2017).

2.22.2 Biotechnological processes in the pharmaceutical industry

The pharmaceutical industry has undergone a significant transformation with the integration of biotechnological processes into drug discovery, development, and production. From the use of recombinant DNA technology to the production of biologics and personalized medicine, biotechnology has revolutionized pharmaceuticals.

Biotechnological processes have revolutionized the pharmaceutical industry, enabling the development of novel drugs and improving existing ones for healthy living. One such process is recombinant DNA technology, which allows for the production of therapeutic proteins like insulin and human growth hormone (Goeddel, 2017). Genetic engineering techniques have also been used to improve the efficacy and safety of pharmaceuticals (Mullard, 2018).

Another biotechnological process used in the pharmaceutical industry is fermentation, which involves the use of microorganisms like bacteria and yeast to produce antibiotics

and other drugs (Demain, 2017). Advances in fermentation technology have improved the yield and purity of these products (Villadsen, 2018).

Biotechnological processes have also been used to develop novel drug delivery systems, such as liposomes and nanoparticles (Allen, 2017). These systems improve the bioavailability and targeting of drugs, enhancing their efficacy and reducing side effects (Zhang, 2018).

In addition, biotechnological processes have been used to develop personalized medicine, tailoring treatments to individual patients' needs (Hamburg, 2017). Pharmacogenomics, the study of how genetic variation affects drug response, has enabled the development of targeted therapies (Wang, 2018)

The integration of biotechnological processes in the pharmaceutical industry presents unique regulatory challenges and ethical considerations. Regulatory agencies such as the FDA and EMA require stringent oversight of biologics, gene therapies, and cell-based therapies to ensure product safety, efficacy, and quality. Ethical concerns surrounding genetic manipulation, informed consent, and data privacy highlight the importance of ethical frameworks and guidelines in biotechnology-driven healthcare.

Biotechnological processes have been the backbone of the pharmaceutical industry, driving innovation in drug discovery, biomanufacturing, and personalized medicine. Understanding the molecular mechanisms of disease, harnessing the power of genetic engineering, and leveraging advanced analytical tools are key to unlocking the full potential of biotechnology in healthcare, continued collaboration between academia, industry, and regulatory agencies.

2.22.3 Biotechnological processes in the mining industry

The mining industry has long been associated with environmental degradation and pollution. However, with the advent of biotechnology, the industry is witnessing a significant shift towards sustainable and eco-friendly practices. Biotechnological processes in the mining industry involve the use of microorganisms, enzymes, and other biological agents to extract metals, clean up contaminated sites, and manage waste.

Bioleaching is a biotechnological process that uses microorganisms to extract metals from ores. This process has gained significant attention in recent years due to its potential to replace traditional chemical leaching methods (Brierley, 2008). Studies have shown that bioleaching can be used to extract a range of metals, including copper, gold, and uranium, using microorganisms such as *Thiobacillus ferrooxidans*, *Leptospirillum ferrooxidans*, and *Sulfolobus acidocaldarius* (Rawlings, 2002).

Bioremediation is the use of microorganisms to clean up contaminated sites. In the mining industry, bioremediation can be used to clean up sites contaminated with heavy metals and other pollutants (Kumar, Nagpal & Kumar, 2011). Studies have shown that microorganisms such as *Pseudomonas putida*, *Bacillus subtilis*, and Rhizobia can be used to remove heavy metals such as lead, mercury, and arsenic from contaminated soil and water (Kao, Chen, Chen & Chen, 2008).

Biosorption is the use of microorganisms or other biological agents to remove metals and other pollutants from wastewater. This process has gained significant attention in recent years due to its potential to remove a range of pollutants from wastewater (Wang & Chen, 2009). Studies have shown that microorganisms such as *Saccharomyces cerevisiae*, *Aspergillus niger*, and *Penicillium chrysogenum* can be used to remove

heavy metals such as copper, zinc, and cadmium from wastewater (Veglio, Beolchini & Gasbarro, 2002).

Biotechnological processes have the potential to revolutionize the mining industry by providing sustainable and eco-friendly solutions for extracting metals, cleaning up contaminated sites, and managing waste. Further research is needed to fully explore the potential of these processes and to overcome the challenges associated with their implementation.

2.22.4 Biotechnological processes in the tanning industry

The tanning industry, historically associated with environmental concerns due to its reliance on chemical processes and waste generation, is increasingly turning to biotechnological solutions for sustainable leather production. Biotechnological processes offer environmentally friendly alternatives for tanning, including enzyme-based treatments, microbial fermentation, and bioremediation of tannery effluents.

Biotechnological processes have been increasingly applied in the tanning industry to improve the efficiency, sustainability, and quality of leather production (Thanikachalam, 2017). One such process is the use of enzymes to enhance the softness and suppleness of leather (Saravanabhavan, 2018). Proteolytic enzymes, such as trypsin and papain, have been used to break down proteins and improve the texture of leather (Senthilvelan, 2017).

Another biotechnological process used in the tanning industry is the application of microbial fermentation to produce tanning agents (Rao, 2018). For example, fungi like *Aspergillus* and *Penicillium* have been used to produce tannins, which are used to stabilize and preserve leather (Vijayalakshmi, 2017).

Biotechnological processes have also been used to develop new tanning agents, such as biotannins, which are more environmentally friendly and sustainable than traditional tanning agents (Sudha, 2018). Additionally, biotechnology has been used to improve the wastewater treatment processes in the tanning industry, reducing the environmental impact of leather production (Thanikachalam, 2018).

Continued research and innovation in genetic engineering, bioprocess optimization, and environmental management are essential for advancing biotechnological processes in the tanning industry.

2.22.5 Biotechnological processes in butter production

Butter production has evolved significantly with the integration of biotechnological processes, offering opportunities for enhanced quality, efficiency, and sustainability. Biotechnology plays a crucial role in various stages of butter production, from raw material selection to post-fermentation processing.

Biotechnological processes in butter production involve various techniques to improve efficiency, quality, and sustainability (Kadam & Singh, 2017). One such technique is the use of microbial lipases to enhance flavour and texture (Kumar & Kumar, 2017). Microbial lipases can hydrolyze milkfat, resulting in a more consistent and desirable flavour profile (Soares & Pereira, 2017).

Another biotechnological process is the use of bacterial cultures to ferment cream, producing compounds that contribute to the characteristic flavour and aroma of butter (Fox, 2017). For example, the bacterial strain *Lactococcus lactis* subsp. *lactis* can produce diacetyl, a key flavour compound in butter (Liu & Yang, 2017).

Additionally, genetic engineering techniques have been explored to modify the fatty acid composition of milk, resulting in improved butter properties (Liu & Yang, 2017).

For instance, scientists have introduced the gene encoding stearoyl-CoA desaturase into dairy cattle, leading to increased levels of unsaturated fatty acids in milk (Zhou & Wang, 2017).

Biotechnological processes play a central role in butter production, influencing fermentation, flavour development, and post-processing steps and hence, continued research and innovation in biotechnology hold promise for further enhancing butter production efficiency, sustainability, and product diversity.

2.22.6 Biotechnological processes in bread production

Bread, a staple food consumed worldwide, undergoes intricate biotechnological processes during production. These processes involve the fermentation of dough by specific microbial cultures, contributing to its texture, flavour, and nutritional properties.

Fermentation is a critical step in breadmaking, where yeast and lactic acid bacteria (LAB) interact to leaven the dough and enhance its flavour. *Saccharomyces cerevisiae*, commonly used as a leavening agent, metabolizes sugars present in the dough to produce carbon dioxide and ethanol, causing dough expansion. LAB species, such as *Lactobacillus sanfranciscensis* in sourdough bread, contribute to flavour development through the production of organic acids and aroma compounds. Fermentation is crucial in bread production, involving yeast and lactic acid bacteria interaction (Hammelman, 2004).

The development of dough structure is facilitated by gluten, a complex protein network formed from the interaction of glutenin and gliadin proteins present in wheat flour. Biotechnological processes, such as kneading and fermentation, promote gluten development by aligning protein strands and trapping gas bubbles produced during

fermentation. Optimal dough consistency and elasticity are crucial for achieving desired bread texture and volume. Gluten formation is essential for dough development and bread texture (Hoseney, 1994)

The selection of microbial cultures significantly influences bread quality and sensory attributes. Commercial yeast strains with desirable fermentation characteristics, such as fast fermentation rates and tolerance to environmental stress, are commonly used in breadmaking. Additionally, the use of sourdough starters containing indigenous microbial populations imparts unique flavour profiles and enhances bread shelf life through acidification and microbial competition. Microbial cultures play a crucial role in bread quality and flavour development (Gobbetti & Gänzle, 2019).

Various processing parameters, including fermentation time, temperature, hydration level, and flour composition, impact bread quality and characteristics. Longer fermentation times allow for increased flavour development and improved dough extensibility, while higher hydration levels result in softer crumb textures. Temperature control during fermentation is crucial for regulating yeast activity and achieving consistent fermentation outcomes. Processing parameters such as fermentation time and temperature influence bread quality (van der Maarel & Kanning, 2017).

Biotechnological advancements in bread production aim to enhance its nutritional value and sensory attributes. The incorporation of whole grains, seeds, and functional ingredients enriches bread with dietary fiber, vitamins, and minerals, offering health benefits to consumers. Moreover, enzymatic modifications, such as amylase treatment to improve dough machinability, optimize bread texture and shelf life. Biotechnological advancements enhance bread quality and nutritional value.

2.22.7 Biotechnological processes in kenkey production

Kenkey, a traditional fermented maize-based dish popular in West Africa, undergoes biotechnological processes that are essential for its flavour, texture, and nutritional properties. These processes involve microbial fermentation, enzymatic activities, and indigenous knowledge passed down through generations.

Microbial Fermentation is a crucial step in kenkey production, where naturally occurring microorganisms ferment the maize dough to produce lactic acid, carbon dioxide, and other metabolites. LAB species such as *Lactobacillus fermentum*, *Lactobacillus plantarum* and *Leuconostoc mesenteroides* are predominant during fermentation, contributing to the souring and flavour development of kenkey. Additionally, yeast species such as *Saccharomyces cerevisiae* may play a role in leavening the dough and enhancing its aroma. Fermentation is a key process in kenkey production, involving the activity of lactic acid bacteria and yeast species (Ocloo & Akonor, 2018).

Various processing parameters, including maize variety, milling techniques, water quality, and fermentation conditions, influence kenkey quality and characteristics. The choice of maize variety affects dough texture, flavour, and fermentation kinetics, with local landrace varieties preferred for their unique sensory attributes. Milling techniques, such as wet milling or traditional stone grinding, impact flour particle size and water absorption capacity, affecting dough consistency and fermentation outcomes. Processing parameters such as maize variety and milling techniques influence kenkey quality and characteristics (Kpodo, Sakyi-Dawson, & Afoakwa, 2020).

Biotechnological processes in kenkey production enhance its nutritional value and health benefits. Fermentation increases the bioavailability of nutrients, including

vitamins, minerals, and amino acids, while reducing antinutritional factors such as phytates and tannins. The presence of beneficial microorganisms in fermented foods like kenkey contributes to gut health, digestion, and immune function, providing potential health advantages to consumers. Fermentation in kenkey production enhances its nutritional value and promotes gut health (Amoa-Awua, Annan, & Jakobson, 2019).

Kenkey production is deeply rooted in West African culture and traditions, with indigenous knowledge passed down through generations. Women, often the primary producers of kenkey, possess valuable expertise in fermentation techniques, dough preparation, and sensory evaluation. Cultural practices such as communal cooking, sharing recipes, and celebrating festivals centered around kenkey highlight its social significance and culinary heritage. Kenkey production embodies cultural significance and traditional knowledge, passed down through generations (Dzah, Dzah, & Akonor, 2017).

In summary, biotechnological processes are integral to kenkey production, shaping its flavour, texture, and cultural significance. The understanding of microbial dynamics, processing parameters, and traditional knowledge is essential for optimizing kenkey-making practices and preserving its culinary heritage. Further research into fermentation kinetics, microbial diversity, and nutritional profiling can enhance our understanding of kenkey production and its role in promoting food security and cultural identity in West Africa.

2.22.8 Biotechnological processes in yoghurt production

Yoghurt is a fermented dairy product that has been consumed for centuries due to its nutritional value and health benefits. The production of yoghurt involves the fermentation of milk by lactic acid bacteria, primarily *Lactobacillus bulgaricus* and

Streptococcus thermophilus. Biotechnological processes have revolutionized the yoghurt production industry by improving the efficiency, safety, and quality of the final product.

Microbial starter cultures are essential in yoghurt production as they ferment the lactose in milk, producing lactic acid and causing the milk to coagulate. Research has shown that the use of defined strain starter cultures can improve the consistency and quality of yoghurt (Tamime & Robinson, 2007). The development of microbial starter cultures with improved acidification rates, texture, and flavor has been a major focus of research in yoghurt production.

Probiotics are live microorganisms that confer health benefits when administered in adequate amounts. The addition of probiotics to yoghurt has become increasingly popular due to their potential health benefits, including improved digestive health and immune system function (Sanders, 2008). Research has shown that the incorporation of probiotics into yoghurt can enhance its nutritional value and health benefits.

Fermentation technologies have played a crucial role in improving the efficiency and quality of yoghurt production. Research has shown that the use of membrane bioreactors and continuous fermentation systems can improve the productivity and consistency of yoghurt fermentation (Dagher, 2014). The development of novel fermentation technologies has the potential to further improve the efficiency and quality of yoghurt production.

Genetic engineering has been used to improve the performance of microbial starter cultures in yoghurt production. Research has shown that the genetic modification of *Lactobacillus bulgaricus* and *Streptococcus thermophilus* can improve their acidification rates, texture, and flavor (Wells & Mercenier, 2008). The use of genetic

engineering in yoghurt production has the potential to further improve the quality and consistency of the final product.

Biotechnological processes have revolutionized the yoghurt production industry by improving the efficiency, safety, and quality of the final product. The use of microbial starter cultures, probiotics, fermentation technologies, and genetic engineering has the potential to further improve the quality and consistency of yoghurt. Further research is needed to fully explore the potential of biotechnological processes in yoghurt production.

2.22.9 Biotechnological processes in cheese production

Cheese production is a complex biotechnological process that involves the controlled fermentation of milk by specific microbial cultures, enzymatic reactions, and subsequent maturation. These processes influence the flavour, texture, and shelf life of cheese.

The fermentation of milk into cheese relies on the activity of various microbial cultures, including lactic acid bacteria (LAB), yeast, and mold species. LAB species such as *Lactococcus lactis*, *Streptococcus thermophilus*, and *Lactobacillus spp.* contribute to acidification, proteolysis, and flavour development during cheese fermentation.

Biotechnological processes in cheese production involve various techniques to improve efficiency, quality, and sustainability (Fox & McSweeney, 2004). Genetic selection and breeding programs utilize genetic information to select and breed dairy cattle with desirable traits, such as high milk production, protein content, and cheese yield (Heinrichs & Connor, 2017). Microbial rennet and enzymes, produced through fermentation, offer a vegetarian alternative to traditional animal-derived rennet (Kumar & Kumar, 2017). Advanced genomics and genome editing tools, like CRISPR, enable

precise modifications to dairy cattle genomes, potentially improving milk composition and cheese production (Van Eenennaam & Young, 2017).

Controlled fermentation processes involve microorganisms like bacteria or mold to develop unique cheese flavours and textures (Fox, 2017). Biotechnological methods and processes can alter milk protein and fat structures, creating novel cheese properties and functionalities.

Additionally, yeast and mold species such as *Geotrichum candidum* and *Penicillium* spp. may be used in the production of specific cheese varieties to impart unique flavours and textures. The fermentation of milk into cheese is driven by the activity of lactic acid bacteria, yeast, and mould species.

Enzymatic reactions play a crucial role in cheese flavour development and texture modification. Proteases and peptidases produced by LAB and indigenous milk enzymes hydrolyze milk proteins (caseins), releasing peptides and amino acids that contribute to cheese flavour and aroma. Lipases catalyze the hydrolysis of milk fat into free fatty acids, which contribute to cheese flavours complexity. Additionally, the activity of microbial enzymes such as rennet (chymosin) leads to the coagulation of milk proteins, forming the curd structure essential for cheese production. Enzymatic reactions contribute to flavour development and texture modification in cheese (Fox & McSweeney, 2017). Starter cultures and adjunct cultures are very essential for controlling fermentation and flavour development in cheese production.

CHAPTER THREE

METHODOLOGY

3.0 Overview

This chapter focuses on the method and procedure used in the study. This includes the research design, area of study, population, sample selection, research instruments, the validity of instruments, reliability of the instruments, the procedure of data collection and analysis, and ethical considerations.

3.1 Research Design

A research design is a plan for conducting research that include procedures for collecting and analysing data (Creswell, 2014). The descriptive research design was used in conducting this study because the research is an evaluative one seeking opinions and attitudes. A cross-section survey design was employed because Form Three biology students in the science classes in different schools were sampled for this study in order to examine the scientific literacy in biotechnology as well as their perceptions, and attitudes towards biotechnology. Survey design is used that allows any issues and questions examined from different perspectives, especially in the level of understanding, perception, and attitude on an issue (Chua, 2006). In addition, survey design is essential in research that involves a large sample size so that the findings can be generalized to the population accurately and effectively. The study employed both qualitative and quantitative methods of data analysis.

3.2 Study Area

Prestea Huni-Valley Municipality in the Western Region of Ghana location formed the area of study. It has a total area of 1791 Km². It borders on the south, Tarkwa/Nsueam Municipality; on the Northwest, Wassa Amenfi East District; on the West, Axim Municipality. The municipality is highly populated since it is a cosmopolitan area. Most

of the people are farmers, and a good proportion of the populace are miners and traders, teachers, and civil servants. Bogoso, Prestea, and Huni-Valley are major towns with Senior High Schools. It also has 29 villages and small towns notably Damang, Aboso, and Bondaye.

3.3 Study Population

The target population refers to all the members who meet the criterion specified for a research investigation. The target population for this study focused on biology students and teachers in Senior High Schools in Prestea Huni-Valley Municipal of the Western region. The accessible population consisted of form three biology students from the three Senior high schools in the municipality. It was important to conduct this research in this Municipality because there is a fair distribution of students from urban and rural areas among these schools. Again, all the schools are in the same category concerning the grading of school.

3.4 Sample and Sampling Techniques

Kim and Cohen (2000) define a sample as a smaller group of subjects drawn from the population in which a researcher is interested in gaining information and drawing conclusions. This means a sample is a subset of a population selected to participate in the study. The research employed the random sampling for the study. This was because according to Robson (2002), this sampling procedure is often an effective practical way to create a representative sample. However, this was achieved in two phases; firstly, each of the three schools was assigned a percentage of the sample based on the total population of form three science students as shown in Table 1.

In phase 2, all the names of form three science biology students were put in the basket and picked randomly if a name is picked that had been picked earlier it was returned to

the basket, and mixing done thoroughly so that picking could be done again until eventually the appropriate sample was picked. This was conducted in all three schools. Three teachers (3); and one hundred and fifty-five (155) students were sampled from the three (3) Senior High schools in the Municipal totalling five hundred and sixteen (516). The sample was determined based on percentages regarding population of each school as shown in Table 1. In all, the respondents add up to one hundred and fifty-eight (158), made up of three (3) male teachers, thirty (30) male students and one hundred and twenty-five (125) female students.

Table 1. Sample size determination

School	Population	Percentage sample	Sample
School A	150	$150/516 \times 155$	45
School B	136	$136/516 \times 155$	41
School C	230	$230/516 \times 155$	69

3.5 Research Instruments

This study made use of tests, questionnaires, and interviews as essential tools for data collection.

3.5.1 Questionnaire

The questionnaire used for this study was deeply rooted in the approaches used by various researchers of existing studies and surveys. The questionnaire consists of three parts, namely: Part A – is to obtain students’- demographic information, made up of gender, academic level, school, and school location; Part B - is items made up of perceptions of biotechnology construct and Part C - items of attitudes toward the biotechnology. Both B and C were based on the Likert scale, 1-5, with 5 options - strongly disagree, disagree, slightly agree, agree, and strongly agree. This odd-

numbered Likert scale can reduce measurement error compared to the use of an even-numbered Likert scale (Bahri et al., 2014).

Part B - Perception towards biotechnology: This part of the questionnaire was developed by the researcher but deeply rooted in the approach used by Latifah et al. (2012) as cited in (Bahri et al., 2014). The selection of this questionnaire was ideal because the constructs measured covered most major aspects in determination towards the acceptance of the biotechnology industry and application. Agriculture and medicine are among the eight biotechnology elements in the Biotechnology Taxonomy Structure proposed by Wells (1994) cited in (Bahri et al., 2014). According to Bahri et al. (2014), both of these elements formed the backbone of the questionnaire because their nature is less technical in comparison with the other six elements. Besides, the products from this biotechnology field are significant to the community, thus, they can be evaluated relevantly by the students (Bahri et al., 2014). For this study, the items were also based on Agriculture and Medicine but in the Ghanaian context, learned in school and through the Media by the students.

Part C - Attitude towards biotechnology: This part of the questionnaire was also developed by the researcher; but were constructed based on the Biotechnology Attitude Questionnaires that has been used by several researchers as cited in (Bahri et al., 2014). This questionnaire was selected for the study because it has concrete and solid constructs to measure the students' attitudes towards biotechnology (Bahri et al., 2014). The items were tailored to measure the affective, cognition, and behaviour domains of attitude about ethics, morals, acceptance, rejections, use, and purchase of biotechnology products as well as the applications in agriculture and medicine as the biotechnology backbone in the questionnaire. In Ghana there have been developments and innovations in agriculture and medicine about biotechnology, hence, employing these items already

used by researchers will be beneficial to this study, considering the goals of the biology syllabus.

3.5.2 Test

Test items were used for this study because they provide a comprehensive assessment of the knowledge, skills, and attitudes being measured. The items were constructed following Bybee's levels of scientific literacy in relation to biology and industry, which are covered in the third-year biology syllabus, as well as biotechnology topics such as cell concepts and genetics. The tests offer an objective, standardized, and efficient way to evaluate students' understanding in this specialized area. Analysis of the test data enables meaningful comparisons and insights into students' biotechnology literacy and areas for development.

For this study, the test was scored out of 100. Means of the students' scores were calculated for the data analysis. The ratings were categorized as follows: a mean score of 7.5-10 was considered very high, 6.5-7.4 was rated as high, 5.0-6.4 as moderate, 4.0-4.9 as low, and any mean score below 3.9 was classified as very low. This grading scale provided a clear benchmark for interpreting students' performance and facilitated consistent evaluation across the sample.

3.5.3 Interview

The researcher also had interviews with teachers to get an in-depth understanding of the topic under study and a way of ascertaining the authenticity of the responses of the students. Semi-structured interviews were used to explore specific themes.

The interviews also captured participant perspectives and hence obtained rich qualitative data and validated findings.

3.6 Validity of the Instrument

Validity refers to the extent to which a study, measurement, or assessment accurately and effectively measures or assesses what it intends to measure (Smith, 2010). It is a crucial concept in research methodology and is often used to evaluate the credibility and trustworthiness of research findings and instruments.

Colleague teachers and course mates were asked to evaluate each item on the questionnaire, items, and the interview guide as essential, and useful.

The questionnaires, test items, and the interview guide were presented to an expert to peruse through and help in reconstruction for validity. This was done to ascertain the validity of test items in terms of content, and external and internal validity as well. Pre-testing was conducted with the form three biology students of Amenfiman Senior High School since they have the same characteristics as the target group to find out unclear and ambiguous questions, and these questions were removed and replaced accordingly. Finally, the questionnaire, tests, and interview guide were validated by my supervisor after the pre-testing.

3.7 Reliability of the Instrument

Reliability, in the context of research and measurement, refers to the consistency, stability, and dependability of a measurement instrument or research method over time and across different conditions (DeVellis, 2016). It signifies the degree to which the same results or outcomes can be consistently obtained when the measurement is repeated.

While preparing the items, the researcher ensured that, the expressions were clear and understandable; the choices were in conformity with each other, and the difficulty level were moderate and hence could be replicated. Again, a good percentage of the

population from another school not part of the selected school for the study were selected to participate in the pilot study for reliability. SPSS 22.0 was used to determine the Cronbach Alpha reliability of the items on the tests, questionnaires, and interview guides. The alpha reliability of the scales ranged from 0.70 to 0.75, indicating a strong internal consistency within each scale (Pallant, 2007).

3.8 Data Collection Procedure

The researcher presented a copy of introductory letter obtained from the University of Education, Winneba, to sought permission from the headmasters of the selected schools three weeks before the study was undertaken. The purpose of the introductory letter was to solicit support and create a good connection between the researcher and the teachers whose students served as respondents. Afterward, there was a brief discussion about the purpose and significance of the study.

The researcher visited the schools in turns within a stipulated period of days and administered the test within the duration of 1hour 30minutes minutes and collected promptly to ensure all the answer booklets were responded to and duly returned and then followed it up with the administration of the questionnaires after about an hour of taken the test. To ensure a high return rate, and to clarify the meaning of some items to students, the questionnaires were administered by the researcher. In all one hundred and fifty-five (155) test item papers and one hundred and fifty-five (155) questionnaires was administered. The researcher also booked appointments with biology teachers and interviewed them on the topic under study a week later.

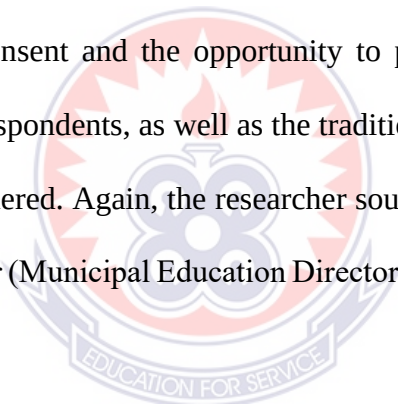
3.9 Data Analysis

Data collected from the field was analysed using descriptive statistics; mean, standard deviation, frequency, and percentage. The items were analysed using the mean score.

That is in the descriptive analysis mean score interpretation was used to determine the level of students' literacy, perception, and attitude toward biotechnology. Also, the Pearson Product-moment Correlation was used to investigate the relationships between literacy and perception and that of literacy and attitudes towards biotechnology. Independent samples t-test was used in comparing literacy levels by gender.

3.10 Ethical Consideration

In all research investigations, ethical considerations play a critical role. According to Suzgo (2002), the ethical implication is a study of systems and practices as seen in the lives of specific people, so the researcher would be open and honest with the respondents when gathering the necessary data. Anybody who was included in the study was given informed consent and the opportunity to participate willingly. Also, the confidentiality of the respondents, as well as the traditions and customs of the selected sample size, was considered. Again, the researcher sought permission from the Senior High School's employer (Municipal Education Director) for some relevant information.



CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Overview

This chapter presents the analysis and interpretation of the data collected from the respondents, following the methodology described in Chapter Three. The primary aim of the study was to investigate the literacy, perceptions, and attitudes of Form Three biology students towards biotechnology in selected Senior High Schools within the Prestea/Huni-Valley Municipality. Specifically, the research objectives were to assess students' biotechnology literacy levels and differences in levels regarding gender, identify their perceptions and attitudes towards biotechnology, and examine the relationships between these factors and their academic performance.

The chapter begins with an analysis of the socio-demographic characteristics of the respondents, providing a context for understanding the sample population. Subsequently, it includes a detailed presentation of the results aligned with the study's objectives, focusing on students' biotechnology literacy, perceptions, and attitudes. This is followed by a statistical analysis of the relationships among these variables and students' performance in biotechnology. The findings are discussed in relation to the research questions, with insights supported by relevant literature, ensuring that the results are contextualized within broader educational and scientific frameworks.

4.1 Socio-Demographic Characteristics

The socio-demographic data offers crucial insights into the composition of the sample, helping to frame the findings on students' literacy, perceptions, and attitudes towards biotechnology. Table 2 highlights significant aspects of the population's gender distribution, age range, and academic levels, which can influence the study's outcomes.

Table 2. Demographic characteristics of students (N = 155)

Variable	Sub-scale	Frequency	Percentage
Gender	Male	30	19.35
	Female	125	80.65
Age	15	4	2.58
	16	9	5.81
	17	25	16.13
	18	61	39.35
	19	35	22.58
	20	10	6.45
	21	8	5.16
	22	3	1.94
Academic level	Year 1	-	-
	Year 2	-	-
	Year 3	155	100.0
Total		155	100.0

Source: Field work (2024)

Firstly, the gender distribution reveals a considerable disparity, with 80.7% of the students being female and only 19.4% male. This significant gender imbalance misaligns with existing research indicating that fewer female students tend to pursue science-related fields compared to their male counterparts, particularly in sub-Saharan Africa (UNESCO, 2017). Gender disparities in science education often stem from socio-cultural norms and stereotypes that discourage female participation in STEM fields (Osborne et al., 2003). The limited male representation in this sample could skew the study's findings, especially in terms of attitudes and perceptions towards biotechnology. It is well-established that gender can influence students' attitudes towards science, with studies showing that male students often display more positive attitudes towards biotechnology and related scientific subjects (Dawson & Schibeci, 2003; Potvin & Hasni, 2014). The underrepresentation of males in this study limits the ability to explore gender-based differences in depth, which could be an important aspect of students' engagement with biotechnology.

The age distribution is concentrated between 17 and 19 years, which collectively accounts for nearly 84% of the participants. Most students are 18 years old (42.1%), followed by 19-year-olds (24.1%), and 17-year-olds (17.2%). This age range is typical for Form Three students in Ghanaian senior high schools, where students typically complete their education at the age of 18 or 19. The presence of older students, particularly those aged 20 and above, may indicate delayed academic progression, possibly due to repeating academic years or interruptions in their education (Acheampong, 2010). Age can influence cognitive development and academic performance, with older students often perceived as more mature and potentially more receptive to complex scientific concepts such as biotechnology (Woolfolk, 2016). However, the impact of age on students' literacy and attitudes towards biotechnology was not a specific focus of this study, but it could be a relevant factor in future research.

The academic level data shows that all the students (100%) are in their third year of senior high school, which is consistent with the study's focus on Form Three biology students. This skewed distribution reflects the educational structure in Ghana, where biotechnology topics are introduced at more advanced levels of biology education, typically in the final year (Curriculum Development Division, 2010). Third-year students are expected to have more exposure to biotechnology concepts, which may influence their literacy, perceptions, and attitudes. This focus on final-year students is supported by research indicating that older students or those in advanced academic stages often exhibit better scientific literacy and more favourable attitudes toward biotechnology compared to younger students (Klop & Severiens, 2007).

To summarize, the socio-demographic characteristics of the sample reveal a predominance of male, final-year students aged between 17 and 19 years. This composition is reflective of broader trends in science education in Ghana, where gender

disparities persist, and age-related differences in academic progression are common. The demographic profile of the students is likely to influence the study's findings on biotechnology literacy, perceptions, and attitudes, particularly in relation to gender and academic exposure. Future studies should aim to address gender imbalances to better explore how both male and female students engage with biotechnology education.

4.2 Research Question 1: Students' Levels of Biotechnology Literacy

The first research objective of this study was to assess the biotechnology literacy levels of biology students in the selected Senior High Schools within the Prestea/Huni-Valley Municipality. This objective is significant as it provides a foundational understanding of students' knowledge and comprehension of biotechnology, which is increasingly relevant in various fields, including health, agriculture, and environmental science (Dawson & Soames, 2006). By identifying the current literacy levels, Teachers can develop targeted interventions to enhance students' understanding and engagement with biotechnological concepts. The findings will also contribute to addressing the broader issue of declining interest in science among students, as highlighted by Aikenhead (2004), and will inform educational strategies that aim to foster positive attitudes toward biotechnology.

To answer this research objective, data were collected using a quantitative approach with the use of test. The test assessed their literacy levels regarding knowledge, understanding and practical applications. The sample consisted of 155 biology students from three public Senior High Schools in the Prestea/Huni-Valley Municipality. Data analysis involved both descriptive statistics and inferential statistics. Descriptive statistics summarized the mean scores for various topics, while inferential statistics, such as an independent samples t-test was employed to compare differences in literacy levels regarding gender. This analytical framework aligns with previous studies that

emphasize the importance of understanding students' literacy levels to enhance educational outcomes (Ibrahim & Babayemi, 2010). By using quantitative data, this study aims to provide a comprehensive overview of biotechnology literacy among students and its implications for educational practice.

Table 3. Descriptive statistics for literacy test

	N	Min.	Max.	Mean	Std. Deviation
Cell concepts	155	3	16	8.44	2.702
Genetics	155	2	14	6.09	2.113
Biology and industries	155	2	14	7.11	2.652
Biotechnology: nominal level	155	0	11	5.22	2.652
Biotechnology: functional scientific literacy	155	0	9	3.85	1.552
Biotechnology: conceptual level	155	0	14	3.68	1.902
Biotechnology: multidimensional level	155	0	12	1.92	1.710

Source: Field work (2024)

Table 3 displays the mean scores across various topics and reveals a nuanced understanding of biotechnology among students, reflecting both strengths and weaknesses in their knowledge base ascertaining the literacy levels. The ratings were categorized as follows: a mean score of 7.5-10 was considered very high (highest), 6.5-7.4 was rated as high, 5.0-6.4 as moderate, 4.0-4.9 as low, and any mean score below 3.9 was classified as very low regarding literacy levels. The highest mean score was observed in cell concepts ($M = 8.44$, $SD = 2.702$), indicating that students possess a solid foundation in cellular biology, which is fundamental to understanding more complex biotechnological applications. This aligns with the findings of Dawson and Soames (2006), who emphasized that a strong grasp of basic biological principles is essential for comprehending advanced topics in biotechnology. Conversely, the mean score for genetics ($M = 6.09$, $SD = 2.113$) suggests that while students have some

understanding, there is still room for improvement. This moderate performance may reflect the complexities associated with genetic concepts, which are often challenging for students (Bruschi et al., 2011).

In terms of biology and industries, the mean score of 7.11 (SD = 2.652) indicates a very good understanding of how biological principles apply to industrial contexts. This finding is significant as it demonstrates that students can connect theoretical knowledge with practical applications, a critical aspect highlighted by Ibrahim and Babayemi (2010), who noted that real-world applications enhance student engagement and comprehension.

However, when examining the biotechnology-specific literacy levels, the results reveal concerning trends. The mean scores for the four aspects of biotechnology literacy - nominal level (M = 5.22, SD = 2.652), functional scientific literacy (M = 3.85, SD = 1.552), conceptual level (M = 3.68, SD = 1.902), and multidimensional level (M = 1.92, SD = 1.710) - indicate a significant gap in understanding biotechnological concepts and their applications. The notably very low mean score in the multidimensional level suggests that students struggle to integrate various aspects of biotechnology into a cohesive understanding, which is crucial for informed decision-making regarding biotechnological innovations (Schibeci, 2000).

These findings resonate with existing literature that highlights the challenges faced by students in grasping complex biotechnological concepts due to inadequate foundational knowledge and negative perceptions towards biotechnology (Aikenhead, 2004). Moreover, the low scores in functional and conceptual literacy levels may reflect broader societal attitudes towards biotechnology, where misconceptions and ethical concerns often overshadow educational efforts (George, 2006).

The disparity between students' strong performance in foundational topics and their weak performance in biotechnology-specific areas suggests an urgent need for educational interventions aimed at bridging this gap. Teachers must focus on enhancing students' understanding of biotechnology through engaging pedagogical strategies that connect theoretical knowledge with real-world applications. This approach aligns with the recommendations from Bruschi et al. (2011) for integrating practical experiences into biotechnology education to foster deeper comprehension. The respondent teachers explained this finding by indicating that students struggle with biotechnology topics, which is echoed in the interview responses. The first respondent (R1) stated, "the more they see, the more the knowledge," emphasizing that practical exposure significantly enhances understanding. This aligns with the quantitative data which suggests that students with limited hands-on experiences tend to perform poorly in biotechnology-specific areas. Moreover, the second respondent (R2) pointed out, "the system that we run now does not permit us to treat most of the topics into details," indicating a curriculum limitation that contributes to students' weak performance. This finding supports the quantitative analysis, which reveals that insufficient coverage of biotechnology topics correlates with lower literacy levels. The need for engaging pedagogical strategies is further supported by the third respondent, R3's observation that "students are always interested but lack practical knowledge," highlighting the necessity for educational reforms that incorporate real-world applications. This reflects Bruschi et al. (2011) recommendation for integrating practical experiences into biotechnology education. Additionally, R1's use of case studies and laboratory experiments to introduce biotechnology demonstrates an effective strategy to bridge the gap between theoretical knowledge and practical application. R1 stated, "I use laboratory experiments like to conduct hands-on bio-technology experiments especially

on DNA extraction,” which illustrates a proactive approach to enhancing student engagement and comprehension.

4.2.1 Differences in literacy levels of fundamental concepts and biotechnology

The analysis of the mean scores for fundamental biological concepts (cell biology, genetics, and biology and industry) compared to the literacy levels of biotechnology (nominal, functional, conceptual, and multidimensional levels) reveals a significant disparity in students’ understanding. The total mean score for fundamental topics, which stands at 7.2133, is markedly higher than the mean score of 3.6675 for biotechnology literacy. This substantial difference suggests that students possess a stronger grasp of basic biological concepts than they do of the more complex and specialized aspects of biotechnology. Such findings indicate a potential gap in students’ understanding, highlighting an urgent need for educational interventions aimed at bridging this divide.

Supporting this finding, R1 emphasized the importance of practical experiences in enhancing understanding, stating, “the more they see, the more the knowledge”. This aligns with the quantitative data suggesting that students’ limited exposure to practical applications contributes to their lower scores in biotechnology literacy. R2 echoed this sentiment by noting that much of the content remains “abstract,” and using videos and real-life examples helps students engage with the material more effectively. This reflects Dawson and Soames’ (2006) assertion that foundational knowledge is critical for understanding advanced biotechnological concepts.

Moreover, R3 highlighted that students often express interest but lack practical knowledge, stating, “students are always interested but lack practical knowledge”. This observation highlights the necessity for educational interventions that bridge the gap

between foundational biology and biotechnology. The qualitative insights from the interviews reinforce the quantitative findings by illustrating how inadequate exposure to real-world applications leads to difficulties in grasping biotechnology concepts.

The literature further supports this need for targeted educational strategies. Bruschi et al. (2011) advocate for integrating practical experiences into biotechnology education to foster deeper comprehension. R1's use of case studies and hands-on laboratory experiments, particularly in DNA extraction, exemplifies an effective strategy to enhance student engagement and understanding. This approach directly addresses the observed gap in literacy levels by connecting theoretical knowledge with practical applications.

Additionally, R2's suggestion to use real-life scenarios, such as addressing agricultural challenges through biotechnology, illustrates how contextualizing lessons can enhance relevance and comprehension. By integrating these methods into teaching practices, Teachers can help students develop a cohesive understanding that bridges foundational biology and its applications in biotechnology.

4.2.2 Differences in literacy levels by gender

In this subsection of the data analysis, how literacy levels in biotechnology vary by gender among the biology students is analysed. Understanding this variation is crucial for identifying specific demographic factor that may influence students' comprehension and engagement with biotechnological concepts. Such analysis not only sheds light on existing differences but also informs targeted educational interventions aimed at enhancing students' literacy in biotechnology. This is significant because literature suggests that socio-demographic factors can significantly impact educational outcomes, particularly in complex fields such as biotechnology (Ibrahim & Babayemi, 2010).

To analyze the differences in literacy levels by gender, an independent samples t-test was conducted. The independent samples t-test allows for the comparison of means between two distinct groups (in this case, male and female students) providing perceptions into whether gender plays a significant role in understanding fundamental and biotechnological concepts. This methodological approach aligns with previous research that emphasizes the importance of understanding how demographic factors influence students' attitudes and performance in science education (Aikenhead, 2004; Schibeci, 2000).



Table 4. Independent samples t-test comparing literacy levels by gender

		Levene's Test for Equality of Variances		T	df	Sig. (2- tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
		F	Sig.						Lower	Upper
Cell concepts	Equal variances assumed	.010	.921	2.908	155	.004	1.558	.536	.500	2.617
	Equal variances not assumed			2.929	44.117	.005	1.558	.532	.486	2.630
Genetics	Equal variances assumed	3.873	.051	2.472	155	.015	1.044	.422	.210	1.877
	Equal variances not assumed			2.059	36.875	.047	1.044	.507	.016	2.071
Biology and industries	Equal variances assumed	1.619	.205	2.714	155	.007	1.432	.528	.390	2.474
	Equal variances not assumed			2.524	40.538	.016	1.432	.567	.286	2.578
Biotechnology nominal level	Equal variances assumed	.011	.917	2.515	155	.013	1.331	.529	.286	2.377
	Equal variances not assumed			2.591	45.337	.013	1.331	.514	.297	2.366
Biotechnology functional scientific literacy	Equal variances assumed	2.327	.129	2.583	155	.011	.799	.309	.188	1.410
	Equal variances not assumed			2.375	40.088	.022	.799	.337	.119	1.479
Biotechnology conceptual level	Equal variances assumed	.663	.417	.806	155	.422	.311	.386	-.452	1.075
	Equal variances not assumed			.737	39.902	.465	.311	.422	-.543	1.165
Biotechnology multidimensio nal level	Equal variances assumed	.079	.779	-.092	154	.927	-.033	.353	-.730	.665
	Equal variances not assumed			-.105	49.082	.917	-.033	.311	-.658	.593

Source: Field work (2024)

The results from the independent samples t-test, as shown in Table 4, indicated significant differences in literacy levels between genders across several topics. For instance, in cell concepts, the mean difference of 1.558 ($p = .004$) suggests that female students outperformed their male counterparts. Similarly, significant differences were observed in genetics (mean difference = 1.044, $p = .015$) and biology and industries (mean difference = 1.432, $p = .007$), indicating a consistent trend where female students demonstrated higher literacy levels than males. This finding aligns with previous studies which suggest that female students often exhibit greater interest and engagement in biology-related subjects, potentially leading to better performance (George, 2006).

However, when examining biotechnology-specific topics through the t-test, only biotechnology: nominal level (mean difference = 1.331, $p = .013$) and biotechnology: functional scientific literacy (mean difference = 0.799, $p = .011$) showed significant gender differences. The lack of significant differences in other areas such as biotechnology: conceptual level and multidimensional level suggests that while foundational biological knowledge may be influenced by gender, more complex aspects of biotechnology literacy may not be as susceptible to such demographic variations.

4.3 Research Question 2: Students' Perceptions of Biotechnology

The second research objective of this study was to identify the perceptions of biology students regarding biotechnology, its applications, and its products. This objective is significant as it sheds light on how students view biotechnology and its relevance in contemporary society, particularly in areas such as health, agriculture, and environmental sustainability (Dawson & Soames, 2006). Understanding students' perceptions is crucial for addressing misconceptions and fostering a more informed and engaged curriculum. Positive perceptions can enhance students' motivation and interest

in biotechnology, which is essential for their academic success and future careers in science-related fields (Ibrahim & Babayemi, 2010).

To address this objective, data were collected using Likert scale items (with a scale ranging from 1-Strongly disagree to 5-Strongly agree) to gauge students' perceptions of biotechnology, its applications, and its products. The questionnaire included items that assessed students' beliefs about the benefits and risks associated with biotechnology, their awareness of ethical issues concerning biotechnological applications in everyday life, and their perceptions towards religious and moral concerns about biotechnological products. Data analysis involved calculating means for the Likert scale responses to summarize the perceptions overall. This is significant because existing literature emphasizes the importance of understanding student perceptions to inform educational practices (Bruschi et al., 2011).

4.3.1 Ethics and risks of biotechnology

This section focuses on the perceptions of biology students regarding the ethical considerations and risks associated with biotechnology. Understanding these perceptions is vital, as they can significantly influence students' attitudes towards biotechnology and their willingness to engage with its applications in various fields (Bruschi et al., 2011). The ethical implications of biotechnology are particularly pressing, given the rapid advancements in this field and the potential societal impacts. The results are displayed in Tables 5 and 6.

Table 5. Descriptives for perceptions towards ethics of biotechnology

	N	Min.	Max.	Mean	Std. Deviation
Biotechnology applications should prioritize ethical considerations over commercial interests.	154	1	5	3.38	1.290
Ethical guidelines should be strictly enforced in all biotechnology research and development.	154	1	5	3.30	1.263
Transparency in biotechnology practices is crucial for maintaining ethical standards.	151	1	5	3.00	1.207
Society should have a say in determining the ethical boundaries of biotechnological advancements.	152	1	5	3.34	1.342
Biotechnology companies should be held accountable for any unethical practices or outcomes.	155	1	5	3.33	1.400
Ethical education and training should be mandatory for professionals working in the field of biotechnology.	154	1	5	3.33	1.316
Collaboration between ethicists and biotechnologists is essential for addressing ethical dilemmas.	154	1	5	3.01	1.209
Public awareness campaigns should be conducted to educate people about the ethical implications of biotechnological advancements.	153	1	5	3.70	1.343
Ethical review boards should have the authority to halt biotechnological projects deemed unethical.	155	1	5	2.90	1.255
Should be used responsibly to minimize potential harm to the environment and society.	151	1	5	3.53	1.334
Informed consent should be obtained from individuals participating in biotechnological research or experiments.	153	1	5	3.33	1.398

Source: Field work (2024)

Table 6. Descriptives for perceptions towards risks of biotechnology

	N	Min.	Max.	Mean	Std. Deviation
The potential risks associated with biotechnology applications outweigh the benefits.	154	1	5	2.77	1.250
Adequate measures are in place to effectively mitigate risks associated with biotechnological advancements.	153	1	5	3.17	1.344
The public should be more informed about the potential risks of biotechnology.	152	1	5	3.50	1.430
Government regulations should be stricter to minimize the risks posed by biotechnological developments.	153	1	5	3.44	1.225
The benefits of biotechnology justify the risks involved in its applications.	151	1	5	2.86	1.285
Stakeholder involvement is crucial in assessing and managing the risks associated with biotechnology projects.	154	1	5	3.17	1.313

Source: Field work (2024)

The results from the Likert scale items assessing perceptions towards the ethics of biotechnology reveal a generally moderate level of agreement among students. For instance, the statement “Biotechnology applications should prioritize ethical considerations over commercial interests” received a mean score of 3.38 (SD = 1.290), indicating that students recognize the importance of ethical considerations but may not fully prioritize them in practice. This finding aligns with the literature suggesting that while students are aware of ethical issues, they often struggle to integrate these considerations into their understanding of biotechnology (Ibrahim & Babayemi, 2010).

Similarly, the mean score for “Ethical guidelines should be strictly enforced in all biotechnology research and development” was 3.30 (SD = 1.263), reinforcing the notion that students support ethical oversight but may lack confidence in its current implementation.

The results also highlight a significant concern regarding public engagement in biotechnological advancements. The statement “Society should have a say in determining the ethical boundaries of biotechnological advancements” garnered a mean score of 3.34 ($SD = 1.342$). This suggests that students believe in the necessity of societal involvement in ethical discussions surrounding biotechnology, echoing findings from Schibeci (2000), who emphasized that public discourse is essential for addressing ethical dilemmas in science education. Furthermore, the higher mean score for “Public awareness campaigns should be conducted to educate people about the ethical implications of biotechnological advancements” (3.70, $SD = 1.343$) indicates a strong desire among students for increased public education on these issues.

In terms of perceived risks associated with biotechnology, responses were more varied. The statement “The potential risks associated with biotechnology applications outweigh the benefits” received a mean score of 2.77 ($SD = 1.250$), suggesting that students generally believe that the benefits of biotechnology may justify its risks. This perspective aligns with existing literature that posits a complex relationship between perceived risks and benefits in public attitudes towards biotechnology (George, 2006). However, concerns about risk management were evident, as indicated by a mean score of 3.44 ($SD = 1.225$) for “Government regulations should be stricter to minimize the risks posed by biotechnological developments.” This reflects a recognition among students that while they see potential benefits, they also advocate for stronger regulatory frameworks to ensure safety and ethical compliance.

Overall, these findings highlight a nuanced understanding among biology students regarding the ethical considerations and risks associated with biotechnology. While there is an acknowledgment of the importance of ethics and public engagement, there

remains a call for greater transparency and stricter regulations to manage perceived risks effectively. This highlights the need for educational interventions that not only enhance knowledge about biotechnological concepts but also foster critical thinking about ethical implications and risk management strategies. Interview responses provide qualitative support for these findings. R1 mentioned, “I try to use real-life experiences like the Covid-19 pandemic,” to engage students in discussions about biotechnology's ethical implications. This approach not only illustrates the relevance of biotechnology in contemporary issues but also encourages students to critically reflect on its societal impacts. R1's emphasis on connecting ethical discussions to real-world events aligns with the quantitative data indicating that students recognize the need for ethical considerations in biotechnology. Similarly, R2 noted that when discussing topics like cloning and genetically modified organisms (GMOs), it is essential to present both the pros and cons, allowing students to make informed decisions based on their perceptions. This method fosters critical thinking and reflects the quantitative findings that suggest students are aware of the ethical dimensions of biotechnology but may require more guidance in navigating these complexities. R3's approach also supports this discussion, as they encourage students to explore career opportunities in biotechnology, which can include ethical considerations related to those fields. By framing biotechnology within the context of potential careers, R3 helps students understand the relevance of ethical discussions in their future professional lives.

The responses from the interviews reinforce the quantitative findings by demonstrating that while students acknowledge the importance of ethics in biotechnology, there is a need for educational interventions that enhance their understanding and critical thinking regarding ethical implications and risk management strategies. This underlines the

necessity for Teachers to integrate discussions about ethics into biotechnology curricula actively, fostering a more comprehensive understanding among students.

4.3.2 Benefits of biotechnology

Understanding the biology students' perceptions of the benefits of biotechnology, which may influence their attitudes and engagement with the subject, is critical as it can shape their willingness to embrace biotechnological innovations in various fields, including healthcare, agriculture, and environmental conservation (Bruschi et al., 2011). Positive perceptions can enhance students' motivation and interest in biotechnology, ultimately leading to improved academic performance and informed decision-making regarding biotechnological applications (Ibrahim & Babayemi, 2010).

Table 7. Descriptives for perceptions towards benefits of biotechnology

	N	Min.	Max.	Mean	Std. Deviation
Biotechnology has the potential to revolutionize healthcare and medicine, offering innovative treatments and cures.	154	1	5	3.37	1.373
Biotechnological advancements can significantly improve agricultural productivity, leading to food security and sustainability.	154	1	5	3.52	1.301
Biotechnology offers promising solutions for environmental conservation and remediation.	151	1	5	3.24	1.247
The use of biotechnology in industry can lead to more efficient production processes and the development of novel materials.	151	1	5	3.34	1.319
Biotechnology has the potential to address global challenges such as climate change and resource depletion.	154	1	5	3.17	1.376
Biotechnological innovations can enhance the quality of life and well-being of individuals and communities worldwide.	151	1	5	3.03	1.419

Source: Field work (2024)

From Table 7, the results from the Likert scale items assessing perceptions towards the benefits of biotechnology reveal generally favourable attitudes among students. For example, the statement “Biotechnology has the potential to revolutionize healthcare and medicine, offering innovative treatments and cures” received a mean score of 3.37 (SD = 1.373). This indicates that students recognize the transformative potential of biotechnology in healthcare, aligning with literature that highlights its role in developing new therapies and improving patient outcomes (Dawson & Soames, 2006). Similarly, a mean score of 3.52 (SD = 1.301) for “Biotechnological advancements can significantly improve agricultural productivity, leading to food security and sustainability” highlights students’ awareness of biotechnology’s impact on addressing global food challenges.

However, perceptions regarding environmental benefits were slightly less optimistic. The statement “Biotechnology offers promising solutions for environmental conservation and remediation” garnered a mean score of 3.24 (SD = 1.247), suggesting that while students see potential in biotechnological applications for environmental issues, their confidence may not be as strong compared to other areas like healthcare and agriculture. This finding resonates with George (2006), who noted that public scepticism often surrounds environmental applications of biotechnology due to concerns about ecological impacts and ethical considerations.

The perception that “The use of biotechnology in industry can lead to more efficient production processes and the development of novel materials” received a mean score of 3.34 (SD = 1.319), indicating a moderate level of agreement among students about the industrial benefits of biotechnology. This reflects an understanding that biotechnology can enhance efficiency and innovation within various sectors, which is essential for fostering a competitive economy.

Interestingly, the statement “Biotechnology has the potential to address global challenges such as climate change and resource depletion” received a lower mean score of 3.17 (SD = 1.376). This suggests that while students acknowledge biotechnology’s relevance in tackling significant global issues, there may be lingering doubts about its effectiveness or applicability in these contexts. This aligns with findings from Schibeci (2000), who emphasized that students often require more education on how biotechnological solutions can be integrated into broader strategies for addressing complex challenges.

Lastly, the statement “Biotechnological innovations can enhance the quality of life and well-being of individuals and communities worldwide” scored a mean of 3.03 (SD = 1.419), indicating a cautious optimism among students regarding the societal benefits of biotechnology. This highlights an opportunity for Teachers to further explore these themes in the classroom, emphasizing real-world applications and success stories that demonstrate biotechnology’s positive impact on communities.

In conclusion, while Form Three biology students generally perceive biotechnology as beneficial across various domains - particularly healthcare and agriculture - there remains room for improvement in their understanding of its environmental applications and broader societal impacts. These insights highlight the importance of integrating discussions about the benefits of biotechnology into educational curricula to foster informed perspectives among students and encourage their active participation in biotechnological advancements.

The responses from the interview provide qualitative support for these findings. R1 emphasized the use of real-life examples to illustrate the benefits of biotechnology, stating, “With genetically modified foods, I let them know that they are part of

biotechnology”. This approach not only connects students with practical applications but also enhances their understanding of biotechnology's relevance in addressing food security issues. R1 further elaborated on agricultural advancements, mentioning “pest resistance to crops that have grown or even drought tolerance” as key examples of how biotechnology can improve agricultural productivity. This aligns with the quantitative findings that show students recognize healthcare and agricultural benefits but may lack awareness of environmental impacts. R2 also highlighted the importance of biotechnology in agriculture, noting that “knowledge of biotechnology with agriculture is relevant to remedy the situation” regarding land degradation due to illegal mining and chemical use. This perspective reflects a growing recognition among students of how biotechnology can address pressing environmental challenges, although their understanding may still be limited. Additionally, R3 mentioned practical applications such as using microbes in food production, stating, “Introduce microbes into corn dough to enhance taste and use microbes to produce yoghurt”. This example illustrates how students can engage with biotechnological concepts through familiar products, thereby fostering a deeper appreciation for the benefits of biotechnology in everyday life.

Overall, the responses from the interviews reinforce the quantitative findings by demonstrating that while students perceive significant benefits of biotechnology, particularly in healthcare and agriculture, there is a need for enhanced educational efforts to improve their understanding of its environmental applications and broader societal impacts. By integrating discussions about these benefits into the curriculum, Teachers can encourage students' active participation in biotechnological advancements and foster more informed perspectives on its potential.

4.3.3 Religious and moral issues of biotechnology

Given the sensitive nature of biotechnological advancements, particularly in areas such as genetic modification and cloning, it is essential to understand how these perceptions can influence students' attitudes and engagement with biotechnology (Ibrahim & Babayemi, 2010). By examining these perceptions, Teachers can better address concerns and foster a more informed dialogue about the ethical implications of biotechnological innovations. The responses from the Likert scale items are presented in Table 8.

Table 8. Descriptives for perceptions towards religious and moral issues

	N	Min.	Max.	Mean	Std. Deviation
Biotechnological advancements should respect religious beliefs and moral values.	154	1	5	3.30	1.296
Ethical considerations should take precedence over religious doctrines in the regulation of biotechnology.	154	1	5	2.94	1.273
Religious leaders should be involved in discussions about the ethical implications of biotechnological developments.	152	1	5	3.32	1.323
Biotechnological interventions should not contradict fundamental religious principles.	154	1	5	3.17	1.332

Source: Field work (2024)

The results from the Likert scale items assessing perceptions towards religious and moral issues reveal a moderate level of agreement among students regarding the necessity of respecting religious beliefs in biotechnological advancements. The statement “Biotechnological advancements should respect religious beliefs and moral values” received a mean score of 3.30 (SD = 1.296), indicating that students generally

believe in the importance of aligning biotechnological practices with ethical standards rooted in religious beliefs. This finding resonates with the literature suggesting that ethical considerations are paramount in discussions surrounding biotechnology, particularly in societies where religious values play a significant role (Schibeci, 2000).

However, there is a notable tension reflected in the mean score for the statement “Ethical considerations should take precedence over religious doctrines in the regulation of biotechnology,” which scored 2.94 (SD = 1.273). This indicates a slightly lower level of agreement among students regarding the precedence of ethical guidelines over religious beliefs. The ambivalence captured here suggests that while students acknowledge the importance of ethics, they may also feel conflicted about prioritizing these considerations over deeply held religious doctrines. This complexity aligns with findings from George (2006), who noted that public attitudes towards biotechnology often reflect broader societal debates about morality and ethics.

The involvement of religious leaders in discussions about biotechnological developments was met with a mean score of 3.32 (SD = 1.323), suggesting that students recognize the value of including diverse perspectives in ethical discussions surrounding biotechnology. This aligns with Bruschi et al. (2011), who emphasized the importance of multi-stakeholder engagement in addressing ethical dilemmas in science education. Furthermore, the statement “Biotechnological interventions should not contradict fundamental religious principles” received a mean score of 3.17 (SD = 1.332), reinforcing the idea that students are conscious of potential conflicts between biotechnological practices and their religious beliefs.

These findings highlight a nuanced understanding among biology students regarding the interplay between biotechnology and religious/moral considerations. While there is

an acknowledgment of the importance of ethical standards, students also grapple with the complexities introduced by their religious convictions.

In conclusion, the analyses conducted for the second research objective reveal a complex interplay between students' perceptions of biotechnology and various socio-ethical dimensions. While the biology students show that they recognize the potential benefits of biotechnology concepts, applications and products, and are aware of the ethical considerations associated with biotechnology, students also express concerns about risks and the need for public engagement in discussions surrounding biotechnological advancements. These insights indicate the importance of integrating ethical education into biotechnology curricula to prepare students for informed decision-making in their future careers and societal roles.

From the interviews, R1 noted, "When we discuss cloning or GMOs, students often have strong opinions based on their beliefs," indicating that personal values and religious beliefs significantly influence their perceptions of biotechnology. This observation aligns with the quantitative findings that suggest students are aware of ethical considerations but may struggle to reconcile them with their moral frameworks. R2 echoed this sentiment by stating, "Some students worry about playing God when it comes to genetic modifications," highlighting the moral dilemmas that arise from biotechnological advancements. This concern reflects a broader apprehension about the implications of manipulating life forms, which is a common theme in discussions about biotechnology ethics. The recognition of such moral issues suggests that students are not only aware of the benefits but are also critically engaging with the potential consequences of biotechnological practices. Additionally, R3 emphasized the importance of public engagement, stating, "We need to talk about these issues openly so everyone understands both sides," which highlights the necessity for transparent

discussions surrounding biotechnological advancements. This perspective aligns with the quantitative findings indicating that students feel a need for greater public discourse on biotechnology's risks and benefits.

Overall, the interviews reinforce the quantitative findings by illustrating how students' perceptions of biotechnology are shaped by socio-ethical considerations, including religious and moral beliefs. These insights highlight the importance of integrating ethical education into biotechnology curricula to equip students with the critical thinking skills necessary for navigating complex moral landscapes in their future roles. Informed discussions on these topics can help Teachers prepare students to engage thoughtfully with biotechnological advancements and their implications for society.

4.4 Research Question 3: Students' Attitudes Towards Biotechnology

The third research objective of this study was to analyse students' attitudes towards biotechnology which is crucial for understanding how perceptions can influence educational outcomes and engagement in this rapidly evolving field. Biotechnology, defined as the use of living systems and organisms to develop or create products, has significant implications in sectors such as agriculture, healthcare, and environmental management (Dawson & Soames, 2006). As students are exposed to biotechnological concepts in their curriculum, their attitudes can shape not only their academic performance but also their future roles as informed citizens and potential professionals in the biotechnology sector.

Understanding students' attitudes towards biotechnology is essential for several reasons. First, positive attitudes can enhance students' motivation and interest in science subjects, which are critical for fostering a scientifically literate society (George, 2006). Furthermore, as biotechnology becomes increasingly integrated into everyday

life, it is imperative that students develop informed perspectives that enable them to navigate ethical dilemmas and societal debates surrounding biotechnological advancements (Ibrahim & Babayemi, 2010). By analyzing these attitudes, teachers and curriculum experts can identify areas for improvement in teaching strategies and curricular content, ultimately leading to better educational outcomes.

To address the third objective, data were collected with Likert scale items to gauge students' attitudes towards biotechnology, its applications, and its products. The questionnaire included items that assessed how students perceive biotechnology applications, ethical considerations, and their overall acceptance of biotechnological innovations. The findings are presented in tables and discussed in the subsequent sub-sections.

4.4.1 Awareness of biotechnology applications

The data presented in Table 9 provides insights into students' attitudes regarding their excitement about medical advantages, understanding of biotechnology applications, and their proactive efforts to seek information in this field.

Table 9. Descriptives for attitudes to awareness of biotechnology applications

	N	Min.	Max.	Mean	Std. Deviation
I feel excited about the potential medical advantages facilitated by biotechnology	152	1	5	3.28	1.257
I have a good understanding of how biotechnology is applied in agriculture, medicine and other fields	153	1	5	3.37	1.185
I actively seek out information about biotechnology through attending lectures, reading scientific articles, or following scientific news	153	1	5	3.27	1.317

Source: Field work (2024)

The first statement, “I feel excited about the potential medical advantages facilitated by biotechnology,” received a mean score of 3.28 with a standard deviation of 1.257. This indicates a moderate level of excitement among students regarding the medical benefits that biotechnology can offer. While there is some enthusiasm, the score suggests that not all students fully appreciate the transformative potential of biotechnological innovations in healthcare. This finding aligns with existing literature that indicates varying levels of excitement and interest in biotechnology, often influenced by individual experiences and educational exposure (George, 2006). To supplement this, R1 mentioned, “I try to use real-life experiences like the Covid-19 pandemic,” to illustrate the medical advantages of biotechnology. This approach not only contextualizes the relevance of biotechnology in contemporary issues but also helps to enhance student excitement and understanding. R2 also highlighted the importance of using videos to capture students' attention, stating that “the mere sight will guide them to know how the thing is done,” indicating that visual aids can enhance their appreciation for biotechnology applications

The second statement, “I have a good understanding of how biotechnology is applied in agriculture, medicine, and other fields,” scored slightly higher with a mean of 3.37 and a standard deviation of 1.185. This suggests that students possess a reasonable understanding of the diverse applications of biotechnology across various sectors. Such awareness is crucial, as it can foster greater acceptance and advocacy for biotechnological solutions in real-world contexts (Ibrahim & Babayemi, 2010). However, the variability indicated by the standard deviation implies that while some students feel confident in their understanding, others may lack comprehensive knowledge, highlighting a potential area for improvement in educational curricula. R3 noted that students are often interested but lack practical knowledge, stating, “Students

are always interested but lack practical knowledge”. This observation emphasizes the need for educational strategies that not only convey theoretical knowledge but also provide practical experiences related to biotechnology applications.

The third statement, “I actively seek out information about biotechnology through attending lectures, reading scientific articles, or following scientific news,” yielded a mean score of 3.27 with a standard deviation of 1.317. This reflects a moderate level of initiative among students to engage with biotechnological topics outside the classroom setting. The willingness to seek out information is an encouraging sign; however, the variability suggests that not all students are equally motivated to pursue additional knowledge. This finding highlights the importance of fostering an environment that encourages curiosity and exploration within the realm of biotechnology. R1 emphasized hands-on learning by stating, “I use case studies and laboratory experiments like to conduct hands-on bio-technology experiments especially on DNA extraction”. This method not only enhances student engagement but also encourages them to seek more information about biotechnological practices actively.

4.4.2 Biotechnology acceptance based on ethics and environmental impact

Table 10. Descriptives for attitudes to biotechnology acceptance based on ethics

	N	Min.	Max.	Mean	Std. Deviation
I trust that biotech companies adhere to ethical standards in their practices	152	1	5	3.14	1.345
I understand the ethical considerations involved in biotechnology and its applications	139	1	5	3.34	1.177
I would consider participating in protests against the use of genetically modified animals	137	1	5	3.20	1.248

Source: Field work (2024)

The data presented in Table 10 provides insights into students' trust in biotech companies, their understanding of ethical considerations, and their willingness to participate in protests against genetically modified animals.

In Table 10, the first statement, "I trust that biotech companies adhere to ethical standards in their practices," received a mean score of 3.14 with a standard deviation of 1.345. This score indicates a moderate level of trust among students regarding the ethical practices of biotech companies. While some students express confidence in the ethical standards upheld by these companies, the relatively low mean suggests that a significant portion remains sceptical. This aligns with existing literature indicating that public trust in biotechnology is often influenced by concerns over ethical practices and transparency (Gaskell et al., 2000). The variability reflected in the standard deviation further emphasizes the differing opinions among students, suggesting that educational efforts should aim to enhance transparency and ethical awareness within the biotechnology sector. R1's comments support this finding, as they noted the importance of addressing scepticism among students: "Some of them are sceptic, so what I usually do is to try and support them... I make them understand that they are all part of biotechnology". This approach highlights the need for Teachers to actively engage students in discussions about ethical practices within biotechnology to build trust and understanding.

The second statement, "I understand the ethical considerations involved in biotechnology and its applications," scored slightly higher with a mean of 3.34 and a standard deviation of 1.177. This finding suggests that students possess a reasonable understanding of the ethical implications associated with biotechnological applications. Such awareness is crucial for fostering informed discussions and responsible decision-

making regarding biotechnology (Ibrahim & Babayemi, 2010). However, the variability indicated by the standard deviation implies that there may still be gaps in understanding among certain students, highlighting an opportunity for educational interventions that focus on ethics in biotechnology. R2 emphasized the importance of presenting both pros and cons when discussing biotechnological topics: “We give them the pros and cons for them to make informed decisions”. This method encourages critical thinking about ethical considerations and supports the quantitative findings regarding students' understanding.

The third statement, “I would consider participating in protests against the use of genetically modified animals,” yielded a mean score of 3.20 with a standard deviation of 1.248. This reflects a moderate willingness among students to engage in activism related to biotechnological issues, particularly concerning genetically modified organisms (GMOs). The variability in responses suggests that while some students may be inclined to advocate for ethical considerations, others may feel less strongly about participating in such actions. This finding aligns with research indicating that attitudes toward activism can be influenced by individual beliefs about the safety and ethics of biotechnological practices (Kolarova, 2014). R3's perspective reinforces this finding, as they noted that “students are always interested but lack practical knowledge,” suggesting that providing more information could empower them to take action on issues they care about.

Attitudes toward biotechnology acceptance based on environmental impact are essential for understanding how students perceive the ecological implications of biotechnological innovations. The data presented in Table 11 provides insights into

students' concerns about biodiversity loss, their confidence in assessing environmental effects, and their engagement in actions related to environmental advocacy.

Table 11. Descriptives for acceptance based on environment impact

	N	Min.	Max.	Mean	Std. Deviation
I am concerned about the potential impact of biotechnology on biodiversity loss	151	1	5	3.05	1.300
I feel confident in my ability to assess the environmental effects of biotechnology innovations	153	1	5	3.02	1.371
I have taken actions (such as signing petitions, joining environmental organizations, or participating in protests) in response to my concerns about the environmental impacts of biotechnology	152	1	5	3.01	1.223

Source: Field work (2024)

In Table 11, the first statement, “I am concerned about the potential impact of biotechnology on biodiversity loss,” received a mean score of 3.05 with a standard deviation of 1.300. This indicates a moderate level of concern among students regarding the ecological consequences of biotechnological applications. While some students express awareness of the potential risks, the relatively low mean suggests that many may not fully grasp the extent of these impacts. This aligns with existing literature that emphasizes the need for greater public awareness regarding the environmental implications of biotechnology (Gaskell et al., 2000). The variability reflected in the standard deviation further highlights differing levels of concern among students, indicating that educational efforts should focus on enhancing understanding of biodiversity issues related to biotechnology.

The second statement, “I feel confident in my ability to assess the environmental effects of biotechnology innovations,” scored slightly lower with a mean of 3.02 and a standard deviation of 1.371. This finding suggests that students possess only a moderate level of confidence in their ability to evaluate the environmental impacts associated with biotechnological advancements. Such confidence is crucial for fostering informed discussions and responsible decision-making regarding biotechnology (Ibrahim & Babayemi, 2010). However, the variability indicated by the standard deviation implies that there may be gaps in knowledge and understanding among some students, highlighting an opportunity for educational interventions aimed at improving skills related to environmental assessment. R3 noted from the interview that students often lack practical knowledge about biotechnological applications, stating, “Students are always interested but lack practical knowledge”. This observation highlights the need for educational strategies that not only convey theoretical knowledge but also provide practical experiences related to assessing environmental impacts.

The third statement, “I have taken actions (such as signing petitions, joining environmental organizations, or participating in protests) in response to my concerns about the environmental impacts of biotechnology,” yielded a mean score of 3.01 with a standard deviation of 1.223. This reflects a moderate level of engagement among students in activism related to environmental concerns surrounding biotechnology. The variability in responses suggests that while some students are inclined to advocate for environmental issues, others may feel less motivated to take action. This finding aligns with research indicating that attitudes toward activism can be influenced by individual beliefs about sustainability and ethical considerations in biotechnology (Kolarova, 2014). R1 from the interview emphasized the importance of fostering engagement by stating, “The more they see, the more the knowledge,” suggesting that exposure to real-

world applications can enhance student motivation to act on their concerns (R1). This highlights the potential for Teachers to inspire greater activism among students by integrating practical experiences into their learning.

4.4.3 Acceptance of biotechnology applications in agriculture and medicine

Table 12. Descriptives for attitudes towards biotechnology in agriculture

	N	Min.	Max.	Mean	Std. Deviation
I feel optimistic about the potential of biotechnology to improve crop yield and address food security issues	152	1	5	3.04	1.291
I understand the benefits of biotechnology in agriculture, such as increased resistance to pests and diseases	153	1	5	3.47	1.192
I actively advocate for the use of biotech solutions in farming practices, such as genetically modified crops	150	1	5	3.34	1.250

Source: Field work (2024)

The data presented in Table 12 provides insights into students' attitudes regarding the potential benefits of biotechnology in agriculture, emphasizing their optimism, understanding, and advocacy for biotechnological solutions.

In Table 12, the first statement, "I feel optimistic about the potential of biotechnology to improve crop yield and address food security issues," received a mean score of 3.04 with a standard deviation of 1.291. This relatively moderate score indicates a cautious optimism among students regarding biotechnology's role in addressing critical agricultural challenges. While some students may recognize the potential benefits, the score suggests that there is also a degree of uncertainty or scepticism. This aligns with existing literature that highlights the mixed feelings often associated with emerging technologies, where optimism is tempered by concerns over risks and ethical

implications (Gaskell et al., 2000). The second respondent during the interview (R2) supports this finding by emphasizing the importance of using real-life examples to illustrate biotechnology's relevance: “We need to use other technological things to produce more food products to feed the nation”. This statement reflects an understanding of the potential benefits of biotechnology in addressing food security, yet it also indicates that students may require further education to fully embrace these innovations.

The second statement, “I understand the benefits of biotechnology in agriculture, such as increased resistance to pests and diseases,” scored higher with a mean of 3.47 and a standard deviation of 1.192. This finding indicates that students possess a better understanding of specific advantages offered by biotechnology, such as pest resistance and disease management. Such awareness is crucial, as it can lead to greater acceptance and advocacy for biotechnological practices in agriculture (Ibrahim & Babayemi, 2010). Teachers can leverage this understanding to further enhance students’ knowledge about biotechnological applications and their importance in sustainable agricultural practices. R1 noted the significance of hands-on experiences in fostering this understanding, stating, “I use laboratory experiments like to conduct hands-on biotechnology experiments especially on DNA extraction”. This means engaging students in practical applications can help solidify their comprehension of biotechnology's benefits.

The third statement, “I actively advocate for the use of biotech solutions in farming practices, such as genetically modified crops,” yielded a mean score of 3.34 with a standard deviation of 1.250. This indicates a moderate level of advocacy among students for biotechnological solutions in agriculture. The variability in responses

suggests that while some students are inclined to support these innovations, others may remain hesitant or opposed due to ethical concerns or lack of information. This aligns with findings from previous studies indicating that advocacy for biotechnology often hinges on individuals' perceptions of its safety and efficacy (Kolarova, 2014). R3's comments reinforce this point: "Students are always interested but lack practical knowledge," suggesting that providing more information could empower them to take action on issues they care about. This means integrating discussions about the ethical implications and practical applications of biotechnology into the curriculum can encourage greater advocacy among students.

Table 13. Descriptives for acceptance of biotechnology applications in medicine

	N	Min.	Max.	Mean	Std. Deviation
I feel hopeful about the potential medical advancements facilitated by biotechnology, such as personalized medicine	152	1	5	3.23	1.189
I understand the benefits of biotechnology in medicine, such as targeted drug therapies and improved diagnostics	153	1	5	3.41	1.189
I actively participate in community discussions about the benefits and risks of biotech applications in healthcare	152	1	5	3.46	1.259

Source: Field work (2024)

Table 13 provides insights into students' hopes for medical advancements, their understanding of biotechnology's benefits in medicine, and their participation in community discussions about these applications.

In Table 13, the first statement, "I feel hopeful about the potential medical advancements facilitated by biotechnology, such as personalized medicine," received a mean score of 3.23 with a standard deviation of 1.189. This score indicates a moderate

level of hopefulness among students regarding the transformative potential of biotechnology in healthcare. While there is some optimism, the mean suggests that not all students fully embrace the possibilities offered by biotechnological advancements. This finding aligns with existing literature that highlights varying degrees of hope and enthusiasm for biotechnological innovations, often influenced by personal experiences and educational exposure (George, 2006).

The second statement, “I understand the benefits of biotechnology in medicine, such as targeted drug therapies and improved diagnostics,” scored slightly higher with a mean of 3.41 and a standard deviation of 1.189. This suggests that students possess a reasonable understanding of specific advantages provided by biotechnology in medical contexts. Such knowledge is crucial for fostering acceptance and advocacy for biotechnological solutions in healthcare (Ibrahim & Babayemi, 2010). However, the variability indicated by the standard deviation implies that while some students feel confident in their understanding, others may lack comprehensive knowledge about these applications.

The third statement, “I actively participate in community discussions about the benefits and risks of biotech applications in healthcare,” yielded a mean score of 3.46 with a standard deviation of 1.259. This reflects a relatively high level of engagement among students in discussions about biotechnological applications in medicine. The willingness to engage in community dialogue is encouraging, as it suggests that students are not only aware of biotechnological issues but are also interested in contributing to conversations surrounding them. This finding supports research indicating that active participation in discussions can enhance understanding and acceptance of complex scientific topics (Kolarova, 2014).

4.4.4 Purchase and use of biotechnology products

Table 14. Descriptives for attitudes to purchase of biotechnology products

	N	Min.	Max.	Mean	Std. Deviation
I feel emotionally drawn to biotech companies and their products due to positive experiences or perceptions	152	1	5	2.86	1.235
I am knowledgeable about the features and benefits of biotech products available in the market	152	1	5	3.41	1.162
I frequently purchase biotech products for personal use	139	1	5	3.24	1.231

Source: Field work (2024)

Table 15. Descriptives for acceptance towards use of biotechnology products

	N	Min.	Max.	Mean	Std. Deviation
I trust biotech companies to produce safe and reliable products	154	1	5	3.25	1.446
I believe that biotech products offer significant benefits to society	154	1	5	3.51	1.200
I am willing to purchase products labelled as biotech or containing GMOs	154	1	5	3.36	1.215

Source: Field work (2024)

The data presented in Table 14 provides insights into students' emotional connections to biotech companies, their knowledge of biotech products, and their actual purchasing behaviour. The first statement, "I feel emotionally drawn to biotech companies and their products due to positive experiences or perceptions," received a mean score of 2.86 with a standard deviation of 1.235. This relatively low score suggests that students do not feel a strong emotional connection to biotech companies or their products. The variability indicated by the standard deviation implies that while some students may

have positive perceptions, many do not share this sentiment. This finding aligns with existing literature that highlights the importance of emotional engagement in consumer behaviour, suggesting that without a strong emotional connection, students may be less likely to support or purchase biotechnology products (Kolarova, 2014). From the interview, R1 supports this observation, noting that, “Some of them are sceptic, so what I usually do is to try and support them” (R1). This indicates that scepticism can hinder emotional engagement with biotechnology products, suggesting that teachers need to address these concerns to foster a stronger connection between students and biotech innovations.

In contrast, the second statement, “I am knowledgeable about the features and benefits of biotech products available in the market,” scored higher with a mean of 3.41 and a standard deviation of 1.162. This indicates that students feel relatively informed about the benefits and features of biotechnology products. Such knowledge is crucial for fostering positive attitudes toward purchasing these products, as informed consumers are more likely to make confident purchasing decisions (Ibrahim & Babayemi, 2010). However, the variability in responses suggests that there may still be gaps in understanding among some students, pointing to an opportunity for educational interventions aimed at enhancing knowledge about biotechnology. R2 emphasized the importance of using engaging resources during the interview: “Using videos will catch their attention... once they see it and see that it is something that relates to them, they capture everything”. This approach can help bridge gaps in knowledge and enhance students' understanding of biotechnology products.

The third statement, “I frequently purchase biotech products for personal use,” yielded a mean score of 3.24 with a standard deviation of 1.231. This reflects a moderate level

of engagement with biotechnology products among students, indicating that while some are willing to incorporate these products into their lives, others may remain hesitant. This finding is significant as it highlights the role of consumer behaviour in the acceptance and success of biotechnological innovations in the market (George, 2006). The variability here also suggests differing levels of comfort and familiarity with biotechnology among students. R3 noted practical applications that resonate well with students: “Yoghurt and cheese are enjoyed by students. I always encourage them to learn about these products from biotechnology during teaching” (R3). This connection between familiar products and biotechnology can enhance student engagement and willingness to purchase such items.

The data presented in Table 15 reveals the mean scores and standard deviations for various statements related to the acceptance of biotechnology products among students. The findings indicate a moderate level of acceptance, which is essential for understanding how these attitudes can influence students’ future decisions regarding biotechnological applications. The first statement, “I trust biotech companies to produce safe and reliable products,” received a mean score of 3.25 with a standard deviation of 1.446. This suggests that while students exhibit a degree of trust in biotech companies, there remains significant scepticism. This aligns with existing literature, which indicates that public trust in biotechnology is often contingent upon perceived risks and benefits (Gaskell et al., 2000). The cautious trust reflected in the data highlights the need for educational interventions that enhance students’ understanding of biotechnological processes and the regulatory frameworks that ensure product safety. R1's comments support this finding, as they acknowledged the scepticism among students: “Some of them are sceptic, so what I usually do is to try and support them”.

This indicates that addressing concerns and building trust through education is essential for fostering acceptance of biotechnology products.

In terms of societal benefits, the statement “I believe that biotech products offer significant benefits to society” scored higher, with a mean of 3.51 and a standard deviation of 1.200. This finding suggests that students recognize the potential positive impacts of biotechnology on societal challenges, such as food security and healthcare advancements. Previous studies have shown that awareness of these benefits can significantly enhance acceptance levels (Ibrahim & Babayemi, 2010). Therefore, emphasizing the contributions of biotechnology in addressing real-world problems could further improve students’ perceptions. R2 emphasized the relevance of biotechnology in addressing agricultural challenges: “We need to use other technological things to produce more food products to feed the nation”. This perspective reflects an understanding of biotechnology's societal benefits and supports the notion that enhancing awareness can lead to greater acceptance.

The willingness to purchase biotech products was assessed through the statement “I am willing to purchase products labelled as biotech or containing GMOs,” which yielded a mean score of 3.36 and a standard deviation of 1.215. This indicates a moderate willingness among students to engage with biotechnology products, highlighting the importance of consumer acceptance for the success of biotechnological innovations (Kolarova, 2014). However, the variability in responses suggests differing opinions among students, pointing to an area where targeted educational strategies could be beneficial in fostering more informed consumer behaviour.

4.5 Research Question 4: Perceptions, Attitudes and Biotechnology Literacy

The fourth objective of this study focuses on examining the co-relationship between students' perceptions, attitudes, and biotechnology literacy. Previous studies have indicated that positive perceptions and attitudes can significantly enhance students' engagement with scientific subjects (Ibrahim & Babayemi, 2010). Therefore, understanding these relationships will contribute to more effective educational practices aimed at improving students' performance in biotechnology. The Pearson Product-Moment Correlation was run to determine the relationship between students' perceptions and literacy in biotechnology and between students' attitudes and biotechnology literacy.

To perform the Pearson Product-Moment Correlation analysis, several assumptions must be met to ensure the validity of the results. First, both variables involved in the correlation must be continuous; in this case, students' perceptions and attitudes are measured on a Likert scale, while biotechnology literacy is a continuous variable.

Second, there should be a linear relationship between the two variables, which can be assessed visually using scatterplots. Third, normality was confirmed by observing Q-Q plots (as seen in Figures 1, 2 and 3), indicating that the data is appropriately distributed (Shevlyakov & Oja, 2016). Finally, the observations were independent of each other, meaning that the responses from one participant do not influence those of another (Field, 2013).

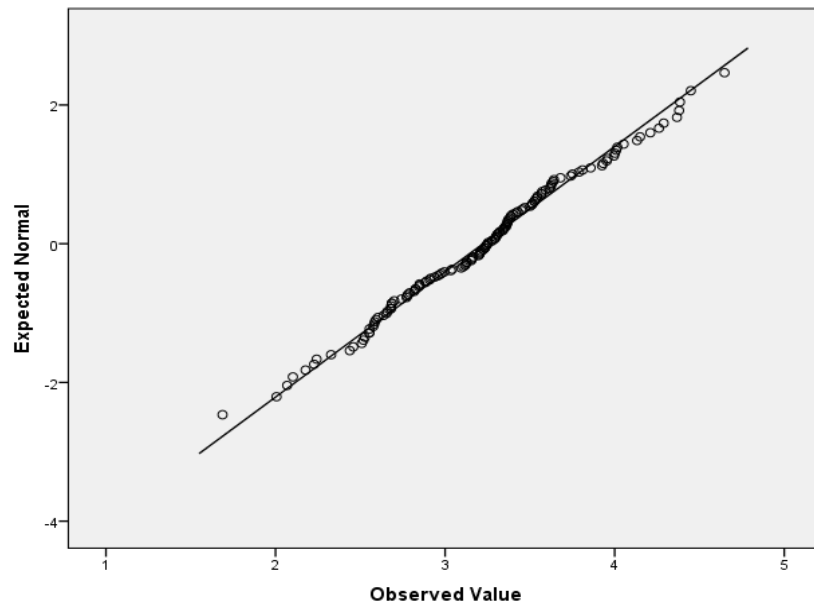


Figure 1. Normal Q-Q plots of students' perceptions

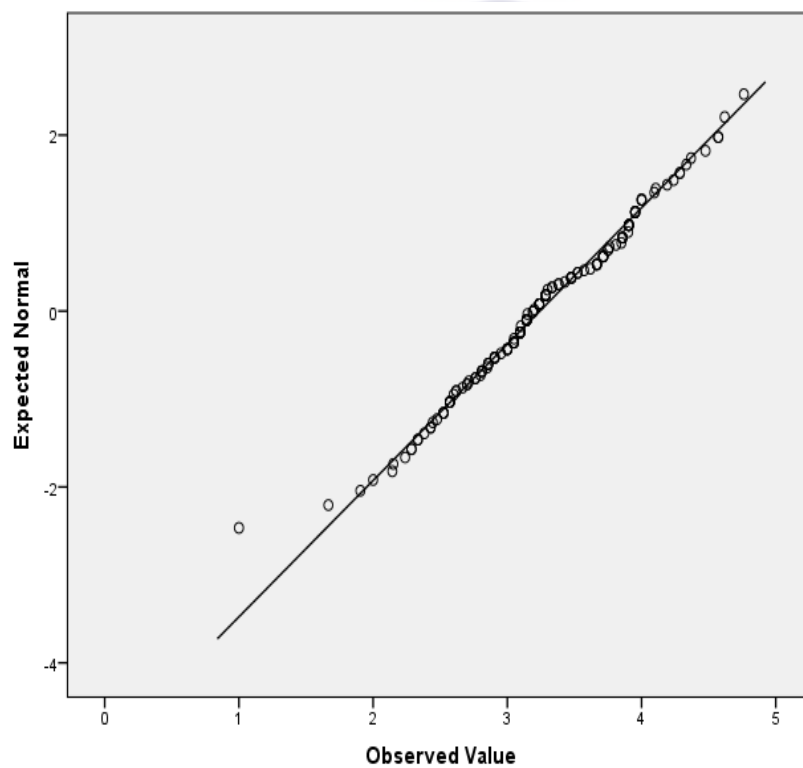


Figure 2. Normal Q-Q plots of students' attitudes

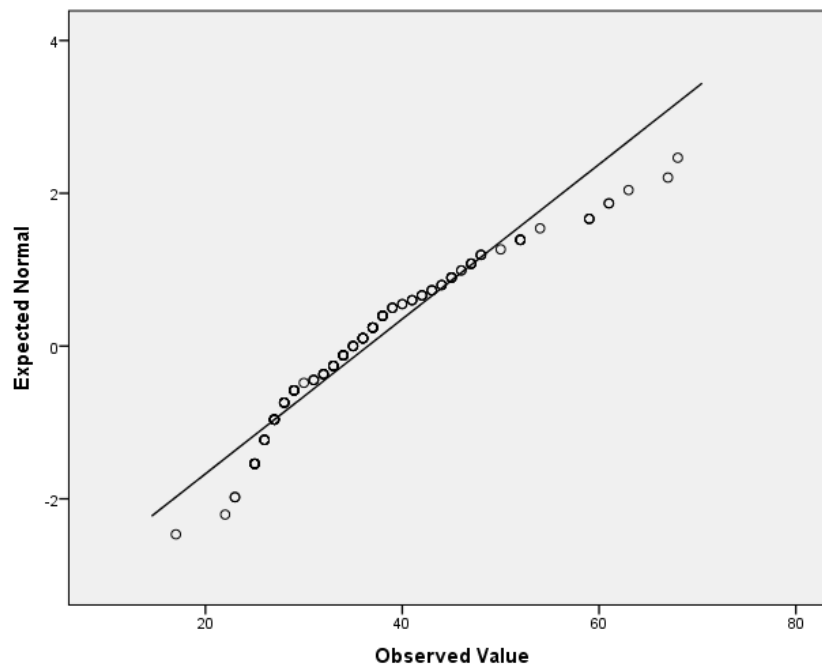


Figure 3. Normal Q-Q Plot of total literacy score

4.5.1 Correlation between students' perceptions and literacy

The correlation analysis between students' perceptions and their total literacy score yielded a Pearson correlation coefficient of $r = 0.022$, which was not statistically significant ($n = 155$, $p = 0.791$). This indicates that there was a non-significant weak positive relationship between students' perceptions of biotechnology and their literacy in the subject. The findings suggest that students' perceptions do not significantly influence their understanding or knowledge of biotechnology. These results conflict with the existing literature that posits a positive correlation between students' perceptions and their engagement with biotechnological concepts. For instance, Ibrahim and Babayemi (2010) argue that positive perceptions can enhance students' motivation and interest in science subjects, which are critical for fostering a scientifically literate society. However, the lack of a significant correlation in this study suggests that merely having favourable perceptions may not be sufficient to improve biotechnology literacy. This finding aligns with previous research indicating that while

perceptions are important, they must be coupled with effective educational strategies to translate into actual knowledge gains (George, 2006).

Table 16. Correlation between students' perceptions and literacy

		Students' perceptions	Total literacy score
Students' perceptions	Pearson Correlation	1	.022
	Sig. (2-tailed)		.791
	N	155	155
Total literacy score	Pearson Correlation	.022	1
	Sig. (2-tailed)	.791	
	N	155	155

Moreover, the absence of a strong relationship may indicate gaps in the educational framework surrounding biotechnology in the curriculum. As noted earlier, many students struggle to connect theoretical knowledge with practical applications, leading to a disconnect between what they perceive about biotechnology and their actual understanding of its principles and applications (Dawson & Soames, 2006). This disconnect could be attributed to insufficient exposure to hands-on experiences or real-world applications of biotechnology during their studies.

Significantly, while the analysis shows no significant correlation between students' perceptions and their total literacy score, it points out the need for educational interventions that bridge the gap between perception and understanding. Enhancing students' experiences with biotechnology through practical applications and immersive learning could foster a more meaningful connection between their perceptions and literacy in the subject. In support of this conclusion, the second respondent during the interview (R2) noted,

“As I said earlier, due to where we find unresolves, everything is just abstract so using the videos will catch their attention, so we just show them a short video to explain the whole thing. So just the mere sight will of the thigh will guide them to know how the thing is done and once they see it and see that it is something that it is related or close to them, they ginger their attention or bring their attention, and this makes them capture or get everything ...”

The responding teacher emphasized the challenges posed by abstract concepts in biotechnology, highlighting the fact that incorporating engaging teaching methods could help bridge the gap between perception and literacy by making complex topics more accessible and relatable to students. Furthermore, R3 pointed out that “students are always interested but lack practical knowledge,” indicating that while students may have positive perceptions about biotechnology, their limited hands-on experience hinders their overall literacy (R3). This reinforces the need for educational strategies that not only present theoretical knowledge but also provide opportunities for practical application.

4.5.2 Correlation between students’ attitudes and literacy

Table 17. Correlation between students’ attitudes and literacy

		Students’ attitudes	Total literacy score
Students’ attitudes	Pearson Correlation	1	-.077
	Sig. (2-tailed)		.335
	N	155	155
Total literacy score	Pearson Correlation	-.077	1
	Sig. (2-tailed)	.335	
	N	155	155

As is shown in Table 17, there was a weak, negative correlation between students' attitudes and their total literacy score, which was not statistically significant ($r = -.077$, $n = 155$, $p = .355$). This finding indicates that students' attitudes toward biotechnology do not have a meaningful relationship with their literacy in the subject. The lack of a significant correlation suggests that students' attitudes, whether positive or negative, do not directly influence their understanding or knowledge of biotechnology.

These results are somewhat concerning given the existing literature that emphasizes the importance of positive attitudes in enhancing students' engagement and performance in science education. For instance, George (2006) highlights that a positive attitude towards science can significantly motivate student interest and improve learning outcomes. Similarly, Ibrahim and Babayemi (2010) argue that students' attitudes towards biotechnology are crucial for fostering motivation and interest in the subject. However, the weak negative correlation in this study suggests that simply having a favourable attitude may not be sufficient to translate into improved literacy in biotechnology. The findings may also reflect broader educational challenges, such as insufficient integration of biotechnology concepts into the curriculum or lack of practical applications that could enhance students' understanding. As noted in the thesis, many students struggle to connect theoretical knowledge with real-world applications of biotechnology (Dawson & Soames, 2006). This disconnect could lead to a situation where students hold positive attitudes toward biotechnology but lack the necessary knowledge to support those attitudes effectively.

Moreover, the absence of a significant relationship between attitudes and literacy may indicate that other factors, such as teaching methods, curriculum design, or access to resources, play a more critical role in shaping students' understanding of biotechnology than attitudes alone. As emphasized in the literature review, effective science education

must encompass not only positive attitudes but also comprehensive exposure to biotechnological concepts and practices to foster genuine understanding and engagement (Schibeci, 2000).

To summarize, while the analysis indicates a weak negative correlation between students' attitudes and their total literacy score, it highlights the need for educational interventions that go beyond fostering positive attitudes. Enhancing students' practical experiences with biotechnology and ensuring robust curricular integration may be necessary to bridge the gap between attitude and literacy. By addressing these areas, Teachers can better prepare students to engage meaningfully with biotechnological concepts and applications. The findings from the interview responses also suggest that enhancing practical experiences with biotechnology and ensuring robust curricular integration may be necessary to bridge this gap. Furthermore, teachers can better prepare students to engage meaningfully with biotechnological concepts and applications. These measures can not only improved literacy but also promote more positive attitudes towards biotechnology among students.

CHAPTER FIVE

SUMMARY, CONCLUSIONS, RECOMMENDATIONS AND SUGGESTIONS FOR FURTHER STUDIES

5.0 Overview

This section synthesizes the findings of the study on the literacy, perceptions, and attitudes of Form Three biology students towards biotechnology in selected Senior High Schools within the Prestea/Huni-Valley Municipality. Specifically, the research objectives were to assess students' biotechnology literacy levels, identify their perceptions and attitudes towards biotechnology, and examine the relationships between these factors and their academic performance. The study sampled 155 senior high school students who were administered a structured questionnaire. The data collected was analysed with descriptive and inferential statistics and presented with discussions in the previous chapter.

5.1 Summary of Findings

The first research objective of this study aimed to assess the biotechnology literacy levels of biology students in selected Senior High Schools within the Prestea/Huni-Valley Municipality. The findings reveal a mixed understanding of biotechnological concepts among students, which is critical for informing educational strategies to enhance engagement and comprehension in this field. The data collected from 155 biology students indicated that the highest mean score was in cell concepts ($M = 8.44$, $SD = 2.702$), demonstrating a solid foundation in cellular biology. This foundational knowledge is essential for grasping more complex biotechnological applications, as supported by Dawson and Soames (2006). In contrast, the mean score for genetics was lower ($M = 6.09$, $SD = 2.113$), suggesting that while students have some understanding, there is significant room for improvement in this area. Further analysis showed that the

mean score for biology and industries was 7.11 (SD = 2.652), indicating a fair understanding of how biological principles apply to industrial contexts. However, concerning biotechnology-specific literacy levels, the results revealed alarming trends: the mean scores were as follows: nominal level (M = 5.22, SD = 2.652), functional scientific literacy (M = 3.85, SD = 1.552), conceptual level (M = 3.68, SD = 1.902), and multidimensional level (M = 1.92, SD = 1.710). These very low mean scores highlight a significant gap in students' understanding of biotechnological concepts and their applications, consequently low literacy levels.

The analysis comparing literacy levels between fundamental biological topics and biotechnology topics showed that the total mean score for fundamental topics was significantly higher at 7.2133 compared to the mean score of 3.6675 for biotechnology literacy. This disparity indicates that students have a stronger grasp of basic biological concepts than they do of more complex biotechnological aspects. Additionally, the study examined differences in literacy levels by gender among the biology students. The independent samples t-test results indicated significant differences in literacy levels between genders across several topics: female students outperformed male students in cell concepts (mean difference = 1.558, $p = .004$), genetics (mean difference = 1.044, $p = .015$), and biology and industries (mean difference = 1.432, $p = .007$). However, for biotechnology-specific topics, significant differences were found only in biotechnology: nominal level (mean difference = 1.331, $p = .013$) and biotechnology: functional scientific literacy (mean difference = 0.799, $p = .011$). These findings highlight the necessity of considering demographic factors when developing educational strategies aimed at improving biotechnology literacy among students.

The second research question focused on understanding students' perceptions of biotechnology, its applications, and its products. Data were gathered using a Likert

scale questionnaire that evaluated perceptions of biotechnology's ethical implications, risks, benefits, and religious considerations. Results were analyzed using descriptive statistics. Students' views on ethics were moderate, with the statement “Biotechnology applications should prioritize ethical considerations over commercial interests” receiving a mean score of 3.38 (SD = 1.290), suggesting that students recognize the importance of ethical conduct in biotechnology but may not fully prioritize it in practice. Similarly, there was support for stricter ethical oversight, as evidenced by a mean score of 3.30 (SD = 1.263) for “Ethical guidelines should be strictly enforced in all biotechnology research and development.” Regarding risks, students expressed concern, with the statement “The potential risks associated with biotechnology applications outweigh the benefits” receiving a mean of 2.77 (SD = 1.250), indicating ambivalence about biotechnology’s risk-to-benefit ratio. On the contrary, students showed stronger support for regulatory measures, reflected in the higher mean score of 3.44 (SD = 1.225) for “Government regulations should be stricter to minimize the risks posed by biotechnological developments.”

When evaluating the benefits of biotechnology, students were generally optimistic. For example, the statement “Biotechnological advancements can significantly improve agricultural productivity” scored a mean of 3.52 (SD = 1.301), highlighting positive perceptions of biotechnology's potential to address food security. Similarly, biotechnology's role in healthcare was acknowledged with a mean score of 3.37 (SD = 1.373) for the statement “Biotechnology has the potential to revolutionize healthcare and medicine.” However, students were slightly less optimistic about biotechnology's environmental contributions, as the statement “Biotechnology offers promising solutions for environmental conservation and remediation” garnered a mean score of 3.24 (SD = 1.247).

Religious and moral considerations were also included in the analysis. Students demonstrated a cautious attitude toward biotechnology's alignment with religious values, with the statement "Biotechnological advancements should respect religious beliefs and moral values" receiving a mean score of 3.30 (SD = 1.296). This suggests that while students believe in the importance of aligning biotechnology with ethical and religious standards, there may be some tension regarding the precedence of ethical guidelines over religious doctrines. Overall, the results of this analysis indicate that students are aware of both the potential benefits and risks associated with biotechnology, though they call for stricter regulatory frameworks and ethical considerations.

The third research question focused on analyzing students' attitudes toward biotechnology, specifically in relation to their awareness of applications, ethical concerns, and willingness to accept biotechnological innovations. A Likert scale was used to measure attitudes across various biotechnological domains such as agriculture, healthcare, and environmental management. Descriptive statistics revealed moderate excitement about biotechnology's potential, with the statement "I feel excited about the potential medical advantages facilitated by biotechnology" receiving a mean score of 3.28 (SD = 1.257). Similarly, students expressed a reasonable understanding of biotechnological applications across fields, scoring 3.37 (SD = 1.185) for "I have a good understanding of how biotechnology is applied in agriculture, medicine, and other fields." However, the responses indicated variability in students' active engagement, as the mean score for "I actively seek out information about biotechnology" was 3.27 (SD = 1.317), implying that while students recognize biotechnology's importance, only some actively pursue more knowledge.

Further analysis highlighted that students have a largely positive attitude toward biotechnology's ethical dimensions. The statement "Biotechnology interventions should not contradict fundamental ethical principles" scored a mean of 3.17 (SD = 1.332), reflecting students' recognition of the ethical concerns surrounding biotechnology. Additionally, the statement "Government regulations should be stricter to minimize the risks posed by biotechnological developments" scored 3.44 (SD = 1.225), indicating students' desire for a more stringent regulatory framework to manage risks associated with biotechnology. This finding is reinforced by responses indicating a strong preference for public awareness campaigns, as the statement "Public awareness campaigns should be conducted to educate people about the ethical implications of biotechnological advancements" scored 3.70 (SD = 1.343). In terms of biotechnology acceptance, students displayed optimism regarding biotechnology's role in agriculture, healthcare, and environmental sustainability. The statement "Biotechnological advancements can significantly improve agricultural productivity" scored 3.52 (SD = 1.301), while the potential of biotechnology to revolutionize healthcare earned a mean score of 3.37 (SD = 1.373). However, students were slightly more cautious about biotechnology's role in addressing environmental challenges, with the statement "Biotechnology offers promising solutions for environmental conservation" scoring a mean of 3.24 (SD = 1.247). Overall, students expressed a balanced view, showing optimism for biotechnology's benefits but advocating for stricter regulations to mitigate potential risks.

These findings indicate that while students are generally supportive of biotechnology and acknowledge its potential to address global challenges, they remain concerned about the ethical and regulatory frameworks governing its application. The data suggest that students' attitudes could be further improved through enhanced education and

engagement initiatives, which could strengthen their understanding of both the benefits and potential risks associated with biotechnology.

The fourth research question investigated the relationship between students' perceptions, attitudes, and their biotechnology literacy, using Pearson's Product-Moment Correlation. This analysis revealed non-significant relationships between these variables. For perceptions, the Pearson correlation coefficient was $r = 0.022$ ($p = 0.791$), indicating an insignificant and weak positive relationship between students' perceptions of biotechnology and their literacy scores. This finding suggests that students' general perceptions of biotechnology, whether positive or negative, do not necessarily influence their biotechnology knowledge or understanding. Despite existing literature, such as studies by Ibrahim and Babayemi (2010), suggesting that positive perceptions can enhance student engagement and understanding in scientific fields, this study did not find substantial support for that conclusion within the context of biotechnology education. Similarly, the relationship between students' attitudes and their biotechnology literacy was also found to be weak and statistically insignificant, with a correlation coefficient of $r = -0.077$ ($p = 0.355$). This negative correlation suggests that students' attitudes, whether favourable or not, do not significantly affect their literacy in biotechnology. These findings were somewhat surprising, given prior research that emphasizes the importance of a positive attitude in enhancing engagement and performance in scientific subjects (George, 2006). The lack of significant relationships between attitudes and literacy highlights the possibility that other factors, such as teaching methods, curriculum design, or exposure to practical applications, may play a more pivotal role in students' biotechnology understanding than attitudes alone.

The results indicate that while positive perceptions and attitudes toward biotechnology are important, they may not be enough to improve literacy on their own. This suggests

a need for more robust educational strategies that incorporate practical experiences and critical engagement with biotechnology topics to close the gap between perception, attitude, and actual understanding of biotechnology.

5.2 Conclusions

The study explored the biotechnology literacy, perceptions, and attitudes of Form Three biology students in selected Senior High Schools in Ghana, aiming to enhance their performance in biotechnology. The findings revealed a significant gap between students' understanding of fundamental biology and more complex biotechnology topics. While students performed well in basic biology areas, their biotechnology literacy scores were notably low, particularly in topics like genetic modification and biotechnological processes. This gap highlights the need for educational reforms that integrate practical biotechnology applications into the curriculum, moving beyond theoretical instruction. To address these gaps, hands-on laboratory experiences and case studies could help bridge the divide between students' knowledge of basic science and their understanding of real-world biotechnological advancements.

Students' perceptions of biotechnology were generally positive, especially regarding its potential to improve agriculture and healthcare. However, there was also clear concern about the risks and ethical implications of biotechnology, with many students advocating for stricter ethical guidelines and regulatory oversight. These concerns reflect a growing awareness among students of the broader societal impacts of biotechnology. Educational initiatives that emphasize the ethical and environmental dimensions of biotechnology are crucial, as they could not only deepen students' understanding but also empower them to engage in informed public debates about biotechnological issues. The inclusion of ethics-based discussions in science education

could foster a generation of students who are not only knowledgeable but also socially responsible in their approach to biotechnology.

In terms of attitudes, students expressed optimism about biotechnology's role in solving global challenges such as food security and healthcare. However, they remained cautious about its environmental impact and the ethical dilemmas it presents, calling for stronger government regulation. This ambivalence suggests that while students recognize the transformative potential of biotechnology, their support is conditional on assurances that its risks are carefully managed. Teachers can leverage this cautious optimism by promoting critical thinking around biotechnology's applications, encouraging students to weigh both its benefits and risks. Such an approach could foster a more balanced and nuanced understanding of the subject.

Interestingly, the study found no significant correlation between students' perceptions or attitudes and their biotechnology literacy. This finding implies that while students may hold positive views about biotechnology, these attitudes do not necessarily translate into better literacy or understanding. This disconnect highlights the importance of not only fostering positive attitudes but also ensuring that students are given the tools to critically engage with the subject matter. More interactive, inquiry-based learning strategies could help translate these positive perceptions into deeper understanding and literacy. The results also suggest that exposure to practical, real-world biotechnology applications is likely more important than attitudes in improving student literacy.

Overall, the study highlights the importance of integrating more practical biotechnology education into the curriculum to improve student literacy. It also emphasizes the need to address ethical and environmental concerns through enhanced regulatory frameworks and public education. By creating a more engaging, practical, and ethically

grounded biotechnology education, students will be better equipped to navigate and contribute to the rapidly evolving field of biotechnology, both academically and as future professionals.

5.3 Recommendations

The findings of this study have led to the following recommendations for the students and the teachers in the study schools:

1. Students had high literacy levels in basic biology but low biotechnology literacy. To address this gap, the biology curriculum should be revised to include more in-depth biotechnology content. This could be achieved through integrating real-world applications, hands-on laboratory work, and case studies that make biotechnology more tangible and relevant. These changes would help bridge the knowledge gap between foundational biology and more advanced biotechnology topics, better preparing students for the demands of modern science.
2. Students were aware of biotechnology's potential but lacked a deep understanding of its ethical implications. Schools should incorporate dedicated ethics modules within biotechnology education to emphasize the social, ethical, and environmental dimensions of the field. These modules could cover topics such as genetic modification, cloning, and the moral considerations of biotechnology applications in agriculture and medicine. Providing this context would help students critically engage with biotechnological advancements and make informed decisions about its ethical implications.
3. There was no significant relationship between students' attitudes toward biotechnology and their literacy in the subject. Teaching strategies should focus on fostering not only positive attitudes but also critical thinking skills through

inquiry-based learning. Encouraging students to actively engage in problem-solving and biotechnology-related experiments could help them move from having favourable attitudes to developing a deeper, more comprehensive understanding of the subject. This approach could translate students' interest in biotechnology into higher literacy and academic performance.

4. Gender differences were observed, with boys slightly outperforming girls in certain areas of biotechnology literacy. Schools should adopt gender-sensitive teaching approaches that encourage equal participation in biotechnology education. Programs aimed at empowering girls in science, including mentorship opportunities, hands-on practical experiments, and collaborative projects, could help to close the gender gap in biotechnology literacy and ensure that both boys and girls develop strong, equal competencies in the subject.
5. The results indicate that while positive perceptions and attitudes toward biotechnology are important, they may not be enough to improve literacy on their own. Schools should adopt more robust educational strategies that incorporate practical experiences and critical engagement with biotechnology topics to close the gap between perception, attitude, and actual understanding of biotechnology

5.4 Suggestions for Further Studies

Firstly, it is advisable for future studies to expand the sample size and include a diverse range of educational institutions across different regions of Ghana. This broader approach would provide a more comprehensive understanding of students' literacy levels, perceptions, and attitudes towards biotechnology, allowing for a more nuanced analysis of how various educational contexts influence student engagement and performance.

Secondly, longitudinal studies should be conducted to assess the long-term effects of biotechnology education on students' literacy and attitudes of the selected schools. By tracking students over time, researchers can gain insights into how sustained exposure to biotechnological concepts impacts their understanding and appreciation of the subject, as well as their ability to apply this knowledge in real-world contexts.

Additionally, future research could explore the integration of biotechnology education with other interdisciplinary approaches. Investigating how biotechnology concepts can be effectively combined with subjects such as ethics, environmental science, or social studies may enhance students' critical thinking and holistic understanding of biotechnological applications.



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APPENDIX A

QUESTIONNAIRE

I am a graduate (M.Phil.) student at the University of Education, Winneba who is conducting a study on SENIOR HIGH SCHOOL BIOLOGY STUDENTS' LITERACY, PERCEPTIONS, AND ATTITUDES TOWARDS BIOTECHNOLOGY. Please be assured that all information given to the researcher will be held in strict confidence and will only be used for research and academic purposes. No names of participants will be included in the study. Please read each question carefully. Indicate your responses by either a tick in the box or by writing in the spaces provided after the item.

Part A – Students Demographic Information

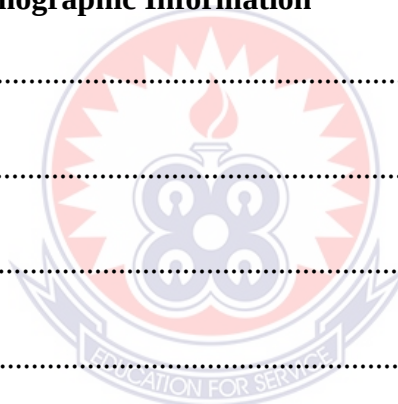
Gender:

Age:

Academic level:

School:

School location:



Part B and C – Perceptions and Attitude towards Biotechnology

Instructions: Please read each statement carefully and indicate your level of agreement or disagreement with each statement based on your perceptions of biotechnology. Use the given Likert scale (SD – Strongly Disagree; D – Disagree; S – Slightly Agree; A – Agree; SA – Strongly Agree) and tick your responses.

B - Perceptions of biotechnology	SD	D	S	A	SA
Perceptions towards ethics					
Biotechnology applications should prioritize ethical considerations over commercial interests.					
Ethical guidelines should be strictly enforced in all biotechnology research and development.					
Transparency in biotechnology practices is crucial for maintaining ethical standards.					
Society should have a say in determining the ethical boundaries of biotechnological advancements.					
Biotechnology companies should be held accountable for any unethical practices or outcomes.					
Ethical education and training should be mandatory for professionals working in the field of biotechnology.					
Collaboration between ethicists and biotechnologists is essential for addressing ethical dilemmas.					
Public awareness campaigns should be conducted to educate people about the ethical implications of biotechnological advancements.					
Ethical review boards should have the authority to halt biotechnological projects deemed unethical.					
should be used responsibly to minimize potential harm to the environment and society.					
Informed consent should be obtained from individuals participating in biotechnological research or experiments.					

Perceptions Towards Risks in Biotechnology	SD	D	S	A	SA
The potential risks associated with biotechnology applications outweigh the benefits.					
Adequate measures are in place to effectively mitigate risks associated with biotechnological advancements.					
The public should be more informed about the potential risks of biotechnology.					
Government regulations should be stricter to minimize the risks posed by biotechnological developments.					
The benefits of biotechnology justify the risks involved in its applications.					
Stakeholder involvement is crucial in assessing and managing the risks associated with biotechnology projects.					
Perceptions towards benefits of biotechnology	SD	D	S	A	SA
Biotechnology has the potential to revolutionize healthcare and medicine, offering innovative treatments and cures.					
Biotechnological advancements can significantly improve agricultural productivity, leading to food security and sustainability.					
Biotechnology offers promising solutions for environmental conservation and remediation.					
The use of biotechnology in industry can lead to more efficient production processes and the development of novel materials.					
Biotechnology has the potential to address global challenges such as climate change and resource depletion.					
Biotechnological innovations can enhance the quality of life and well-being of individuals and communities worldwide.					
Perception toward religious and moral	SD	D	S	A	SA
Biotechnological advancements should respect religious beliefs and moral values.					
Ethical considerations should take precedence over religious doctrines in the regulation of biotechnology.					

Religious leaders should be involved in discussions about the ethical implications of biotechnological developments.					
Biotechnological interventions should not contradict fundamental religious principles.					
Part C - Attitudes Toward Biotechnology	SD	D	S	A	SA
Acceptance of the use of biotechnology products					
I am open to using biotechnology products to improve my daily life.					
I believe that biotechnology products have the potential to address pressing societal needs effectively.					
I would consider taking medicines produced by genetically modified microorganisms					
Attitudes toward acceptance of biotechnology application in agriculture	SD	D	S	A	SA
I believe that integrating biotechnology into agriculture can lead to increased crop yields and food security.					
I am supportive of using biotechnology to develop crops that are more resistant to pests and diseases.					
I think that biotechnology has the potential to reduce the need for chemical pesticides and fertilizers in agriculture					
I am open to the idea of genetically modified organisms (GMOs) as a means to address agricultural challenges and improve crop traits.					
Attitudes toward awareness of biotechnology applications	SD	D	S	A	SA
I feel well-informed about the various applications of biotechnology in different fields such as medicine, agriculture, and industry.					
I believe that increasing public awareness about biotechnology applications is essential for informed decision-making and societal progress.					
I am interested in learning more about the potential benefits and risks associated with biotechnology advancements.					
I think that educational initiatives should be implemented to enhance understanding of biotechnology and its implications among the general population.					

Attitudes toward the purchase of biotechnology products	SD	D	S	A	SA
I feel confident that biotechnology products undergo thorough testing to ensure they meet safety and quality standards before being sold.					
I prioritize purchasing biotechnology products that align with my values and contribute positively to society					
I am willing to purchase biotechnology products if they offer clear advantages over traditional alternatives.					
I believe that biotechnology products are worth the investment due to their potential benefits and advancements.					
I trust that regulatory agencies adequately assess the safety and efficacy of biotechnology products before they are made available for purchase.					
It is safe for humans to consume the genetically modified organisms that are available at supermarkets					
Attitudes toward biotechnology acceptance based on ethics	SD	D	S	A	SA
I believe that genetically modified animals have a poorer quality of life than traditionally bred animals.					
Ethical principles should play a significant role in determining the acceptability of biotechnology applications in society.					
I would consider participating in protests against the use of genetically modified animals					
Attitude towards Acceptance and rejection of biotechnology based on environmental impacts	SD	D	S	A	SA
I am more likely to accept biotechnology if it demonstrates a positive impact on the environment, such as reducing pollution or conserving natural resources.					
Concerns about potential negative environmental effects influence my willingness to reject certain biotechnology applications.					
I believe that thorough environmental assessments should be conducted before implementing biotechnology projects to mitigate adverse effects.					
Attitudes toward Acceptance of biotechnology applications in the medical field	SD	D	S	A	SA

I am supportive of incorporating biotechnology advancements in the medical field to improve diagnosis and treatment options.					
I would consider supporting genetic modification of organisms if they are good for the environment					
I am open to accepting biotechnology-based therapies and interventions if they demonstrate efficacy and safety in clinical trials.					
Microorganisms are harmful to be used in the medical field.					



APPENDIX B

INTERVIEW GUIDE

I am a graduate (M.Phil.) student at the University of Education, Winneba who is conducting a study on USING STUDENTS' LITERACY, PERCEPTIONS, AND ATTITUDE TO IMPROVE FORM THREE BIOLOGY STUDENTS' PERFORMANCE IN BIOTECHNOLOGY. Please be assured that all information given to the researcher will be held in strict confidence and will only be used for research and academic purposes. No names of participants will be included in the study. Please listen attentively and respond appropriately to each question.

QUESTIONS:

1. Do you incorporate the topic of technology into your teaching?
2. How do you introduce Biotechnology to your students? And what strategies do you use to make it engaging and comprehensible?
3. Are there specific techniques or resources you utilize to enhance students' understanding and appreciation of biotechnology concepts?
4. How do you encourage critical thinking and ethical reflection among your students when discussing biotechnology?
5. Have you observed any shift in students' attitude towards biotechnology over time and if so, how do you address these changes in your teaching approach?
6. How do you address these changes in your teaching approach?
7. Can you share examples of how you integrate real-world biotechnology applications into your lessons to illustrate their relevance and impact?

8. What challenges have you encountered in teaching biotechnology, particularly concerning students' literacy levels or pre-conceived notions about the subject?
9. How do you assess students' comprehension and attitudes toward biotechnology, and how do you tailor your instruction based on their responses?
10. Are there specific bio-technology products or innovations that you find resonate particularly well with students' and how do you leverage these in your teaching?
11. How do you stay updated on developments and advancements in the field of biotechnology, and how does this inform your instructional practices?



APPENDIX C

TEST

I am a graduate (M.Phil.) student at the University of Education, Winneba who is conducting a study on USING STUDENTS' LITERACY, PERCEPTIONS, AND ATTITUDE TO IMPROVE FORM THREE BIOLOGY STUDENTS' PERFORMANCE IN BIOTECHNOLOGY. Please be assured that all information given to the researcher will be held in strict confidence and will only be used for research and academic purposes. No names of participants will be included in the study.

Gender: Age:

Academic level: School:

INSTRUCTION: Read the questions carefully and answer all questions. This test consists of four sections (Cell concept, genetics, biology and industry, and biotechnology). Each section comprises of true or false, multiple-choice, and theory questions. For the true or false questions, state whether the statements are true or false by underlining your option; for the multiple-choice questions, choose and circle from the alternatives a – d, the correct answer, and for theory questions, provide concise answers to fill the spaces provided.

CELL CONCEPTS

1. According to cell theory, all cells are produced from pre-existing cells.
TRUE\FALSE
2. The purpose of mitosis is to repair damaged tissues. TRUE\FALSE
3. Human cells undergoing mitosis have 46 chromosomes. TRUE\FALSE
4. Meiosis is the type of cell division that produces gametes. TRUE\FALSE
5. Genetic recombination in meiosis reduces the number of chromosomes in daughter cells. TRUE\FALSE
6. Mitosis is responsible for growth and tissue repair in multicellular organisms.
TRUE\FALSE

7. Spindle fibers during cell division transport nutrients and waste products within the cell. TRUE\FALSE
8. Which of the following nitrogenous bases is found in RNA but not in DNA?
- a) Adenine (A) b) Thymine (T) c) Uracil (U) d) Cytosine (C)
9. What is the function of messenger RNA (mRNA) in the process of protein synthesis?
- a) It carries amino acids to the ribosome b) It carries genetic information from the nucleus to the cytoplasm
- c) It catalyzes the formation of peptide bonds d) It acts as a structural component of ribosomes
10. Which enzyme is responsible for synthesizing RNA molecules during transcription?
- a) DNA polymerase b) RNA polymerase c) Ligase d) Helicase
11. What is the primary function of transfer RNA (tRNA) during translation?
- a) To carry genetic information from the nucleus to the cytoplasm b) To transcribe DNA into RNA
- c) To carry amino acids to the ribosome d) To catalyze the formation of peptide bonds
12. Which process involves the decoding of mRNA into a specific sequence of amino acids to form a protein?
- a) Transcription b) Translation c) Replication d) Transformation
13. How does DNA differ from RNA in terms of structure?
- a) DNA contains ribose sugar, while RNA contains deoxyribose sugar
- b) DNA is single-stranded, while RNA is double-stranded
- c) DNA contains the nitrogenous base uracil, while RNA contains thymine
- d) DNA forms a double helix, while RNA forms a single-strand
14. What is the function of ribosomal RNA (rRNA) during protein synthesis?

a) To carry amino acids to the ribosome b) To catalyze the formation of peptide bonds

c) To transcribe DNA into RNA d) To provide a structural framework for ribosomes

15. Which of the following is NOT a component of a nucleotide?

a) Nitrogenous base b) Phosphate group c) Deoxyribose sugar d) Peptide bond

16. How does RNA differ from DNA in terms of function?

a) RNA stores genetic information, while DNA carries out protein synthesis

b) RNA carries genetic information, while DNA carries out protein synthesis

c) RNA forms a double helix, while DNA forms a single strand

d) RNA is involved in DNA replication, while DNA is involved in transcription

17. What is the role of DNA polymerase during DNA replication?

a) To synthesize new DNA strands b) To separate the DNA double helix into single strands

c) To carry amino acids to the ribosome d) To catalyze the formation of peptide bonds

18. Which of the following is a purine nitrogenous base found in DNA?

a) Adenine b) Guanine c) Thymine d) Uracil

19. What is the significance of complementary base pairing in DNA replication?

a) It ensures the accuracy of DNA replication b) It prevents mutations from occurring

c) It increases the stability of the DNA double helix d) It promotes the formation of new nucleotides

20. What is a cell?

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GENETICS

20. DNA is the molecule that carries genetic information in cells. TRUE\FALSE
21. Alleles are alternative forms of a gene that can lead to different traits. TRUE\FALSE
22. DNA replication is the process that produces genetically identical daughter cells. TRUE\FALSE
23. Meiosis involves the exchange of genetic material between homologous chromosomes. TRUE\FALSE
24. Genetically modified organisms (GMOs) have altered genetic material through biotechnology. TRUE\FALSE
25. Genes are segments of DNA that code for specific traits. TRUE\FALSE
26. What role do enzymes play in genetic processes?
- a) They regulate gene expression
 - b) They catalyze biochemical reactions involved in DNA replication and repair
 - c) They transport genetic material within the cell
 - d) They determine an organism's genetic makeup
27. What is the purpose of genetic mutations?
- a) To create genetic diversity
 - b) To prevent DNA replication
 - c) To inhibit gene expression
 - d) To maintain genetic stability
28. What is the central dogma of molecular biology?
- a) DNA is transcribed into RNA, which is translated into proteins
 - b) RNA is transcribed into DNA, which is translated into proteins
 - c) Proteins are transcribed into DNA, which is translated into RNA
 - d) Proteins are transcribed into RNA, which is translated into DNA
29. What is the function of mRNA in genetic processes?
- a) To carry amino acids during protein synthesis
 - b) To provide the template for DNA replication

- c) To carry genetic information from the nucleus to the cytoplasm
- d) To catalyze biochemical reactions within the cell

30. How do biotechnologists use genetic engineering techniques?

- a) To create genetically identical copies of organisms
- b) To alter the genetic makeup of organisms for specific purposes
- c) To study the genetic diversity of populations
- d) To prevent genetic mutations

31. Which process involves the transmission of genetic information from parent to offspring?

- a) Meiosis
- b) Mitosis
- c) Fertilization
- d) DNA replication

32. a. Briefly explain how the process of meiosis contributes to genetic diversity in sexual reproduction

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32. b. outline the significance of chromosome number.

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BIOLOGY AND INDUSTRIES

33. The use of microbial inoculants to enhance soil fertility is a common biotechnological method in soil conservation. TRUE\FALSE

34. Biotechnology cannot contribute to sustainable fishing practices. TRUE\FALSE

35. Genetic modification of crops to absorb toxins is a biotechnological application utilized in soil remediation. TRUE\FALSE

36. Aquaculture does not benefit from biotechnology in improving fish nutrition. TRUE\FALSE

37. Biotechnology helps in mitigating the environmental impact of fishing activities.
TRUE\FALSE

38. Dehydration is not a food preservation method that involves the removal of water from food to inhibit microbial growth. TRUE\FALSE

39. Genetic modification does not contribute to crop improvement in the food industry by enhancing crop yields and resistance to pests. TRUE\FALSE

40. What role do biofilms play in water treatment systems?

- a) They reduce microbial growth b) They increase water turbidity
- b) They enhance filtration efficiency d) They prevent chemical reactions

41. What role do microorganisms play in the water treatment process?

- a) They add color to water b) They remove dissolved oxygen
- c) They break down organic matter and pollutants d) They increase water turbidity

42. Which technology is commonly used to treat wastewater in sewage treatment plants?

- a) Reverse osmosis b) Ultraviolet (UV) disinfection c) Anaerobic digestion
- d) Electrochemical oxidation

43. How does the use of nitrogen-fixing bacteria benefit crops?

- a) By promoting soil erosion b) By increasing nitrogen pollution in waterways
- c) By providing plants with a readily available source of nitrogen
- d) By depleting the soil of essential nutrients

44. Which of the following is a renewable source of biological fuel generated from organic matter such as plant residues?

- a) Natural gas b) Coal c) Ethanol d) Petroleum

45. How does the process of biodiesel production differ from that of ethanol production?

- a) Biodiesel is produced from animal fats, while ethanol is produced from sugar crops.

- b) Biodiesel is a liquid fuel, while ethanol is a gaseous fuel.
- c) Biodiesel is produced through transesterification, while ethanol is produced through fermentation.
- d) Biodiesel has a higher energy density than ethanol.
46. Which of the following is a potential environmental benefit of using algae-based biofuels?
- a) Increased carbon dioxide emissions b) Reduced dependence on fossil fuels
- c) Habitat destruction d) Water pollution
47. State two reasons why biological knowledge is required for the growth of industries.
-
-

BIOTECHNOLOGY

Nominal level of scientific literacy

47. AIDS is a genetic disease. TRUE\FALSE
48. Only when we eat GM food we eat genes. TRUE\FALSE
49. A high production of vitamins by fruit is only possible by genetic manipulation. TRUE\FALSE
50. A yogurt is a biotechnological product. TRUE\FALSE
51. Genetic material exchange between different species is primarily possible by
- a) Manipulation in the laboratory b) Natural selection c) Environmental pollution
d) Hybridization
52. The most powerful toxic substances are primarily:
- a) Naturally occurring b) Synthetic compounds
- c) Genetically modified organisms d) Artificial additives
53. GMOs are typically associated with:
- a) High nutritional value b) Low environmental impact

- c) Minimal regulatory oversight d) Potential presence of toxic substances

54. In the kidney cells genome, information about the color primarily refers to:

- a) Genetic disorders b) Pigment production c) Organ development
d) Waste elimination

55. a. What is biotechnology?

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55. a. All known Bacteria are harmful. Yes or No. Explain your answer

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Functional Scientific Literacy in Biotechnology Concept:

56. It is possible to change the genetic characteristics of a plant to make it more resistant to a given plague. TRUE\FALSE

57. Through genetic modification, foods with higher nutritional values can be achieved. TRUE\FALSE

58. Insulin is obtained by the use of genetically modified (GM) bacteria. TRUE\FALSE

59. Chemically, the genetic material (DNA) is identical in all organisms. TRUE\FALSE

60. Which of the following best describes the application of biotechnology in the pharmaceutical industry?

- a) Using microorganisms to ferment dairy products b) Producing enzymes for leather tanning
c) Synthesizing antibiotics and medicinal compounds d) Enhancing the growth of bacteria in sewage treatment

61. What role do microorganisms play in the production of cheese?

- a) They break down milk fat to produce butter

- b) They ferment lactose to produce lactic acid and coagulate milk proteins
- c) They extract minerals from the raw ingredients
- d) They promote the growth of molds on the surface of cheese

62. How are microorganisms utilized in the mining industry?

- a) Breaking down organic matter in mine waste
- b) Extracting metals from ores through bioleaching
- c) Producing enzymes for pharmaceutical drug development
- d) Filtering contaminants from industrial wastewater

63. How are microorganisms employed in sewage treatment processes?

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B Conceptual level of scientific literacy

64. How do microorganisms contribute to the fermentation process in the production of yogurt?

- a) By breaking down milk fat to produce butter
- b) By fermenting lactose to produce lactic acid and coagulating milk proteins
- c) By extracting minerals from raw ingredients
- d) By promoting the growth of molds on the surface of the product

65. What role do microorganisms play in the tanning industry?

- a) They produce enzymes that break down animal hides
- b) They ferment sugars to produce tanning agents
- c) They facilitate the extraction of collagen from plant sources
- d) They enhance the growth of bacteria on leather surfaces

66. Which of the following industries commonly utilizes microorganisms in the production process?

- a) Automotive manufacturing
- b) Textile production
- c) Construction industry

d) Aerospace engineering

67. What is the primary purpose of using microorganisms in the food industry?

a) To create artificial flavors and colors b) To enhance food preservation and fermentation

c) To increase the acidity of food products d) To improve the texture of food items

68. Biotechnology primarily focuses on studying the behavior of animals in their natural habitats. TRUE\FALSE

69. In the pharmaceutical industry, synthesizing antibiotics and other medicinal compounds is a common application of microorganisms. TRUE\FALSE

70. Microorganisms are involved in the mining industry by breaking down organic matter in mine waste. TRUE\FALSE

71. Explain how microorganisms contribute to the production of biofuels

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Multidimensional Scientific Literacy Level in the Biotechnology Concept:

72. The primary microorganism involved in the fermentation process for making cheese is yeast. (True/False)

73. Biotechnological processes used in bread making to facilitate dough rising include pasteurization. (True/False)

74. In the production of butter, lipase is responsible for breaking down the milk fat into butter. (True/False)

75. Which biotechnological process is used in the production of bread to improve dough elasticity and volume?

a) Fermentation b) Genetic engineering

c) Polymerase chain reaction (PCR) d) Cell culture

76. What is the primary microorganism involved in the fermentation process for making kenkey, a traditional Ghanaian dish?

a) Yeast b) Lactic acid bacteria c) Mold d) Bacteria

77. What environmental impact does the mining industry have on microbial communities?

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78. What are the potential risks associated with the release of genetically modified organisms (GMOs) into the environment?

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79. What environmental impact does the pharmaceutical industry have on microbial resistance?.....

