Available online at: https://jurnal-fkip.ut.ac.id/index.php/ijrse/issue/archive
**International Journal of Research in STEM Education (IJRSE)**
ISSN 2721-2904 (online)
Volume 7 Number 1 (2025): 136 - 150

# High School Learners' Misconceptions in Genetic Engineering and their Possible Causes

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**Abstract**

Several studies have explored learners' misconceptions in genetics. However, few have explored learners' misconceptions in genetic engineering, especially in the context of Lesotho. This study sought to find the common misconceptions learners hold about genetic engineering and their possible causes. The study employed qualitative case study in which convenience sampling was used to identify the participating school and class. A class of thirty-four learners and their teacher, participated. Data were gathered using observations, pre-test, post-test, and semi-structured interviews. Thematic approach was used to analyse and present data. The findings revealed that learners held misconceptions regarding the gene concept, Deoxyribonucleic acid (DNA) concept as well as language misconceptions pertaining to the process of isolation. The possible causes of learners' misconceptions were identified as vast and unfamiliar scientific terminology, lack of teaching/learning resources, inadequate learners' biology textbooks and teachers' incompetence in genetic engineering content and the use of ineffective teaching strategies.

**Keywords**: *Learners, Misconceptions, Genetic Engineering, Science Education, Secondary School Biology*



## INTRODUCTION

Lesotho General Certificate of Secondary Education (LGCSE) curriculum includes biology (B0180) with a purpose of offering opportunity to learners of different abilities and educational needs (Ministry of Education and Training, (MOET), 2023) to acquire skills that benefit them daily. However, learners' achievement in biology has remained low for several years, suggesting that, among other things, learners have challenges. According to Makoti (2015), learners' poor performance in biology may be attributed to their pre-conceptions which according to Etobro & Banjoko, (2017) may not be aligned with conceptions of the scientific community. In cases where learners' conceptions conflict with those of the scientific community, learners are said to hold "alternative conceptions" or "misconceptions" (Etobro & Banjoko, 2017). In this study, the researchers adhered to the use of the word "misconceptions" when learners' conceptions conflict with the acceptable scientific ones.

Ahmed et al. (2018), Etobro and Banjoko, (2017) and Suryanti et al. (2018) established that misconceptions may be tenacious and inhibit conceptual understanding. It is therefore imperative that instructional strategies used by teachers should identify and deal with learners' prior knowledge which may include misconceptions since it is an important factor that affects their construction of new concepts (Etobro & Banjoko, 2017). The same authors further attested that for learners to have proper conceptual understanding of scientific phenomena, they must have accurate prior knowledge which will allow proper assimilation and accommodation of scientifically approved concepts.

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DOI: https://doi.org/10.33830/ijrse.v7i1.1769

Learners' misconceptions have been explored in different topics in biology, including genetics (Osman et al., 2016; Vlckova et al., 2016; Nelson-Ebimie, 2023). However, there is scarce literature on learners' misconceptions in genetic engineering in Lesotho.. For example, the Examination Council of Lesotho (ECoL) biology examiners' reports (ECoL, 2017, 2018) established that learners have misconceptions in genetic engineering. The problem was further highlighted by a diagnostic pilot study carried out in Lesotho where in-service teachers indicated that not only is genetic engineering challenging to learners, but to them as well, hence the prevalence of misconceptions. However, it is not clear from the local studies in Lesotho, what the learners' misconceptions and their possible causes are in genetic engineering. Consequently, this research aims to investigate the common high school biology learners' misconceptions in genetic engineering and their possible causes.

## History of teaching and learning of genetic engineering

Genetic engineering, also known as genetic modification (Wikandari et al., 2021) or genetic manipulation, (Sîrbu & Iordache, 2014) is a process where scientists alter the genetic material of an organism to achieve specific changes in its characteristics (MOET, 2023: Suryanti et al., 2018). This may involve directly modifying the DNA within an organism's cells by adding a gene from a different species (Siritantian, 2022). For example, a gene that controls production of human insulin can be extracted and inserted into bacterial DNA to produce human insulin on a commercial scale (MOET, 2023)

The teaching and learning of genetic engineering in schools began to take shape in the 1970s and 1980s as the field of genetic engineering was rapidly developing (Kessinger, 2013). According to Robert and Baylis (2003), Stanley Cohen and Herbert Boyer developed recombinant DNA technology in 1973 and this marked a significant breakthrough of the concept. This led to the first genetically modified organisms, which became important topics in biology education. The 1980s marked the integration of genetic engineering into the curricula (Almeida and Diogo, 2019). In 1983 the first genetically modified plant, a tobacco plant with an antibiotic-resistant gene, was developed (Kessinger, 2013). This practical example helped illustrate genetic engineering concepts in classrooms. In the 2000's the advent of CRISPR-Cas9 gene-editing technology revolutionized genetic engineering, making it a crucial part of modern biology education (Almeida and Diogo, 2019). Currently, genetic engineering is a fundamental part of biology curricula, with a focus on both theoretical knowledge and practical applications.

The history of genetic engineering education reflects the rapid advancements in the field and the ongoing efforts to keep educational content up-to-date and relevant. However, with that long milestone in the teaching and learning of the concept, research in biology education reflects a number of possible causes of misconceptions in genetic engineering (Almeida & Diogo, 2019).

## Learners' misconceptions in genetic engineering

Etobro and Banjoko (2017) established that PSTs in Nigeria had misconceptions such as a lack of understanding of basic terms, confusing chromatids with chromosomes, or replicated chromosomes with un-replicated chromosomes. On the other hand, Vlckova et al. (2016) showed that Czech high school learners had misconceptions regarding the concepts of DNA, gene, and chromosome. The same learners also had challenges with interconnections of the concept of DNA, gene, and chromosome. Although these challenges were established in genetics, they are seen as applicable in genetic engineering because the concepts of gene, and DNA permeate the topic of genetic engineering.

Suryanti et al. (2018) found that in Indonesia, learners had misconceptions in genetic engineering although they did not articulate these misconceptions. Unlike Suryanti et al. (2018), Machová and Ehler (2023) articulated that Czech learners had misconceptions regarding gene expression, confused genes, DNA and chromosomes. The learners also misunderstood genetic information as relating to information about neurones and axons, because they did not clearly comprehend the role of DNA in a cell. Since the misunderstood concepts are prerequisite to genetic engineering, learners might carry on these misconceptions to genetic engineering. Additionally, Wisch et al. (2018) revealed that learners had misconceptions about recombinant DNA and gene expression after transformation. Learners took it that proteins store genetic information. Osman et al. (2016) discovered that Lebanese G7-12 learners misunderstood genetic engineering to only have positive effects, yet they could not justify this. These learners also had misconceptions relating to how genetic engineering helps in plant breeding. Some of these learners also had a misunderstanding that genes are found on chromosomes and genes determine traits while DNA determines identity.

## Possible causes of learners' misconceptions in genetic engineering

One of the possible causes of learners' misconceptions in genetic engineering is teacher' inadequate knowledge about genetic engineering. For example, literature reports that some teachers have not learned genetic engineering either at high school or tertiary level (Troupe et al., 2018; Yasin et al., 2018). Accordingly, some have inadequate subject content matter knowledge (Elladora et al., 2024). Consequently, they pass on inadequate or inaccurate information to learners, thus misconceptions. Similarly, Alanazi (2023) established that Saudi teachers had limited knowledge about biotechnology of which genetic engineering is a subtopic. Therefore, it can be inferred that teachers have inadequate knowledge about genetic engineering. Vuran et al. (2020) further suggested that some teachers may have inadequate knowledge about teaching materials that can enhance effective learning of genetic engineering. From these suggestions, it can be deduced that learners will have learning difficulties, including misconceptions in genetic engineering because the quality of learning is dependent on the quality of teaching. Furthermore, Kaharaman, (2020) avers that some teachers with inadequate knowledge attested to facing challenges in the teaching of genetic engineering.

Another possible cause of misconceptions is the way of teaching. Etobro and Banjoko (2017), Ilyas and Saeed (2018) and Osman et al. (2016) attest to misconceptions being passed to learners during teaching. These authors highlight that teacher centred pedagogies such as lecture method, easily pass misconceptions from the teacher to learners. This occurs because the teacher solely determines what they pass to learners, without much input from learners, thereby failing to confront their wrong scientific conceptions. Purbosari and Astuti (2023) and Jin and Ouyang (2019) on the other hand suggest that using teaching methods that include multimedia, and flow charts can enhance comprehension of learners and therefore reduce misconceptions. Chen et al. (2016) attest that multimedia tools can substantially improve classroom discourse and improve learners' critical thinking skills.

Yet another factor that can lead to learners' misconceptions is lack of teaching and learning resources or facilities as well as curriculum that is not well articulated (Osman et al., 2016). As Bonde, et al, (2014) put it, when schools lack adequate infrastructure such as laboratories or computer programmes such as simulations, learners' conceptual understanding is inhibited, thereby leading to retention of misconceptions. For example, Alanazi (2023) revealed that some teachers felt that they were not ready to teach biotechnology, and even those who felt ready blamed absence of equipped science laboratories to aid them in effectively teaching biotechnology, resulting in misconceptions. It seems the situation persists because Elladora et al. (2024) reported similar findings where misconceptions were attributed to lack of teaching and learning resources.

Research has also pointed to textbook as another primary resource that leads to misconceptions (Osman et al., 2016). Freire et al. (2013) found that teachers and learners relied on outdated shallow textbooks, resulting in misconceptions. Additionally, the textbooks lacked coherence, used inaccurate vocabulary, unclear images as well as unnecessary concepts and details that hindered deep understanding (Osman et al., 2016). On the other hand, Çimer (2012) noted that even when textbooks were up to date, they were written in English, a foreign language which learners had to contend with.

The situation has persisted because Tshuma and Sanders, (2015) established that learners' interaction with books resulted in some misconceptions. Bariş and Kirbaşlar (2015) also articulated that when textbooks do not sufficiently and adequately cover course material, learners get inaccurate information, thus misconceptions.

Literature also attributes some possible causes of learners' misconceptions to abundance of foreign terms such as gene, genotype and plasmid which contribute to the abstract nature of the topic (Etobro & Banjoko, 2017; Fauzi & Mitalistiani, 2018). Etobro and Banjoko (2017), further established that English language skills can also be causes of misconceptions. For example, in a case where English language is the language of instruction and the learners or sometimes even the teachers are not proficient in it (Mokotso, 2016), misconceptions result. Furthermore, Etobro and Banjoko, (2017) found that misconceptions at times may emanate from learners' immediate environment. Alanazi (2023), Gerçek (2020), Kooffreh et al., (2021) and Occelli and Valeiras (2021), identified curriculum as a possible cause of misconceptions wherein they found that Saudi curriculum was deficient in biotechnological concepts hence resulted in learners' inadequate knowledge about biotechnology and genetic engineering.

Based on reviewed literature, it seems that learners harbour a lot of misconceptions about genetic engineering. The misconceptions seem to emanate from teachers who have inadequate knowledge, the methods of teaching employed, inadequate teaching and learning resources as well as the abstract nature of the subject matter. However, the literature reviewed shows a gap in learners' misconceptions and their possible causes in the context of Lesotho.

### Research Objectives

Understanding learners' misconceptions is fundamental to enhancing science education, especially in complex and rapidly evolving topics like genetic engineering. In the context of secondary school biology education in Lesotho, where conceptual misunderstandings are prevalent, identifying the nature and sources of these misconceptions is critical. This study aims to systematically examine the conceptual barriers learners face and provide evidence-based strategies for improved instruction. Accordingly, the objectives of this study are as follows:

1. To identify the most common misconceptions about genetic engineering held by high school biology learners in the Mafeteng District, Lesotho.
2. To investigate the possible causes of learners' misconceptions in genetic engineering, including instructional methods, teacher competence, textbook content, and learning resources.
3. To explore practical recommendations that can help teachers and curriculum developers improve learners' conceptual understanding of genetic engineering.

## RESEARCHMETHODOLOGY

### Theoretical Framework

This research is underpinned by the theory of constructivism that views learning as a conceptual change (Posner et al., 1982). According to this theory, learners actively construct knowledge from their experiences through changing their conceptual status. Learners use the processes of assimilation and accommodation (Ahmed et al., 2018) to construct or reconstruct their knowledge. That is, learners resolve the dilemma, caused by incoming knowledge, by either taking the new conception as is against their existing conception or replacing the existing with the incoming, thereby fostering conceptual change.

On the other hand, the teacher guides and supports learners in their learning journey, rather than simply delivering content. The teacher encourages learners to reflect on their learning experiences, helping them to internalize and apply what they have learned. By integrating constructivist principles into genetic engineering education, teachers can create a more engaging and effective learning environment that fosters deeper understanding and critical thinking.

### Research Design

This study employed a qualitative approach because it studies human behaviour in the context in which it occurs (Cohen et al., 2018) with the purpose of seeking deep understanding and interpretation of human behaviour from the perspective of the participants. The study employed a case study design in which the focus was one grade 12 class of biology learners, who were conveniently sampled. This afforded the researcher an opportunity to use multiple methods of gathering data such as the use of tests, observations, and semi structured interviews (Cohen et al., 2018). These data collection methods enabled participants to discuss their misconceptions and perceptions regarding genetic engineering in more detail. High school biology learners were targeted because they engage directly with genetic engineering as a sub-topic of inheritance in the biology (0180) syllabus in Lesotho. In this study one school was chosen in Mafeteng district, close to one researcher's place of residence. A class of 34 biology learners, 18 boys and 16 girls, who were aged between 16 and 18 years, participated.

Data were collected using audio recorded observations, pre- and post-tests as well as semi structured interviews. Learners wrote a genetic engineering pre-test based on LGCSE (B0180) syllabus. Teaching followed in two periods of one hour each. Learners then wrote a post-test after which scripts were analysed thematically to identify misconceptions and their possible causes. Thereafter, six learners were selected for interviews based on their level of understanding as reflected by the quality of their responses to the test items. To triangulate data gathered from observations, pre-test and post-test, the teacher was also interviewed.

## FINDINGS AND DISCUSSION

### Misconceptions in genetic engineering

The study aimed to explore common misconceptions held by learners about genetic engineering and their possible causes. The study found that learners had misconceptions related to processes associated with genetic engineering, took genetic engineering as leading to the formation of new species and that it occurs only in micro-organisms. Learners also held misconceptions relating to the gene concept as well as the DNA concept and held language misconceptions relating to the process of isolation. Below is a detailed account of the common misconceptions.

### Processes associated with genetic engineering.

Learners were asked a multiple-choice question that demanded them to choose a process that is not associated with genetic engineering and justify their choice. The following are some responses from some of them to this effect.

> *L 20: Translation is not associated with genetic engineering because translation does not occur in genetically modified organisms.*
>
> *L 24: Translation is not associated with genetic engineering because there is no need for movement of organisms.*

L 20's response shows inadequate knowledge, a factual misconception because translation can occur in all organisms whether genetically modified or not. Learner 24 on the other hand exhibited a misconception in which he associated translation with movement. This might be a preconceived idea from a mathematical concept of translation. In genetics, translation has to do with the ribosome reading of the genetic code in messenger ribonucleic acid (mRNA).

Notably, none of the learners demonstrated comprehension of this matter even though in the pre-test 1 of the learners had demonstrated understanding.

## Genetic engineering leads to formation of new species and it occurs in micro-organisms only

Another misconception was that genetic engineering leads to formation of new species and that it occurs in micro-organisms only. The following are some of their responses to show this point.

> L 13: *Genetic engineering involves combining DNA from different species to produce a specific species*.
>
> L 33: *Genetic engineering involves combining DNA from different species because two micro-organisms are combined*.

L 13's response indicates that he misunderstood genetic engineering as leading to formation of new species whereas it does not. Instead, it simply alters the genome of the organism not the species. L 33 on the other hand restricted genetic engineering to micro-organisms only, which is scientifically inaccurate because genetic engineering can occur even in other organisms such as maize plants. Both responses show a factual misconception – a limitation in their knowledge and understanding.

This study similar to Suryanti et al. (2018) found that learners harboured misconceptions in genetic engineering. However, unlike Suryanti et al. (2018) who did not articulate the misconceptions found, this study provides details of the common misconceptions found among learners. Unique to this study are the misconceptions where learners stated that translation is not associated with genetic engineering whereas it is and where they also stated that genetic engineering leads to formation of new species and occur only in microorganisms. According to Posner et al. (1982), learners might have failed to assimilate or accommodate knew knowledge, hence the misconceptions.

## The gene concept

Another misconception related to the gene concept, and it was demonstrated by 15 learners. When asked to explain the term "target gene" in the post-test, some responded thus:

> *L 10: A target gene is a gene that is aimed at being changed in that is a gene that is going to be joined with the cut plasmid of the bacterium.*
>
> *L 18: Cutting is the removal of a gene with insulin by enzymes called endonucleases and removal of small piece from plasmid by the same enzyme.*
>
> *L 25: Target gene is a gene that is used in genetic engineering that contains the wanted hormone.*

Learner 10's response indicates a conceptual misunderstanding whereby the learner stated that the target gene is the gene "aimed at being changed" whereas a target gene is not being changed, rather it is used to change the genetic makeup of an organism. It is either being removed or added into the genome of an organism. Learners 18 and 25 also exhibited conceptual misunderstanding. The learners stated that the "gene with insulin" and "gene that contains a hormone", which stem from a misunderstanding of how a gene controls production of a hormone such as insulin. These findings resemble those of Etobro & Banjoko, (2017), although their focus was on PSTs and Fauzi & Mitalistiani,

(2018) who identified misconceptions relating to the gene concept, although they were relating it to the concept being foreign to learners and therefore abstract.

## The concept of DNA

Another misconception relates to the concept of DNA where learners seemed to confuse DNA with gene. This misconception surfaced when they were asked to describe recombinant DNA. In response some stated;

*L 1: Recombinant DNA is a DNA that is combined with another strand of DNA from other organisms.*

*L 3: Recombinant DNA is a combination of DNA and a plasmid.*

The responses from L 1 and L3 show conceptual misunderstanding of a gene as a section of DNA and DNA. Learner 1 stated that DNA strands from different organisms are combined and learner 3 said that DNA is combined with a plasmid while the combination is between a target gene and DNA strand of another organism or plasmid. A similar misconception was noticed during classroom discussion. Following is a record of the discussion:

*T: A recombinant DNA is made by combining the target gene, which in this case is the human gene responsible for production of insulin with a cut plasmid.*

*Learner asked for clarification:*

*Learner 16: So sir, does it mean that we take the human DNA and combine it with the bacterial plasmid?*

*T: No, we only use the gene which was cut from the human DNA.*

*L 16: Sir, isn't a gene a section of DNA?*

*T: It is.*

*L 16: If it is, then a gene is a DNA.*

*T: A gene is a section of DNA. It is a small unit that builds up DNA. So, when it is removed from a DNA it is not called a DNA, but a gene.*

From this conversation, it is indicative that L 16 confused DNA with a gene. She thought that a section is the same as a whole, which is incorrect. In this case a section is a gene while a whole is a DNA molecule. This highlights that L 16 harbours conceptual misunderstanding.

Yet another example where one of them confused DNA and the gene was when they were asked to explain the process of cutting in genetic engineering. The example follows:

*L 7: Cutting is the removal of DNA from a target gene.*

L7 confused DNA with gene, instead of saying a gene is extracted from DNA, they said a DNA is removed from a gene, a conceptual misunderstanding. These findings resonate with those of, Vlckova et al. (2016) and Machová and Ehler (2023) wherein learners could not establish the interconnections among the concepts; gene, DNA, and chromosome.

## Language misconception

Other identified misconceptions in genetic engineering involve the process called isolation.

Regarding this process, learners predominantly exhibited a language misconception whereby they explained the process from their everyday English language understanding. Their responses were as follows:

Isolation

*L 9: Isolation is the process in which the target gene is separated from other genes.*
*L 14: Isolation means removing a target gene from an organism and putting it somewhere safe.*

These responses show language misconception whereby the learners explained isolation from the linguistic point of view which was still the case in the pre-test. In genetic engineering, isolation refers to identification of the target gene not detaching the gene from other genes. The same responses also have a connotation of conceptual misunderstanding whereby the learners confused the process of isolation with the process of cutting in genetic engineering.

In summary, the most common misconceptions among learners related to processes associated with genetic engineering, genetic engineering as leading to formation of new species and it being a process that occurs only in micro-organisms. In addition, learners had misconceptions relating to the gene concept, and DNA concept. They also exhibited language misconceptions pertaining to the process of isolation in genetic engineering.

## Causes of misconceptions

Regarding possible causes of misconceptions, the study found the following possible causes of learners' misconceptions: vast and unfamiliar scientific terminology, lack of teaching/learning resources, inadequate content in learners' biology textbooks, the teacher's incompetence with the content, and use of ineffective teaching strategies.

***The vast and unfamiliar scientific terminology***

In the post-test learners were asked to explain the process cutting, and some responded thus:

*L 7: cutting is the removal of DNA from a target gene.*

The learners' response shows a conceptual misunderstanding. DNA is confused with a gene, due to unfamiliar and abstract nature of the molecules involved. Asked to express his opinion about genetic engineering, the teacher said:

*"…The abstract and vast terminology used in this subtopic is challenging to learners and teachers alike. It challenges the teacher on how to help learners to conceptualise it."*

These findings reveal the unfamiliarity of terminology in genetic engineering that makes both learning and teaching challenging. Even during learners' interviews, they confirmed to have challenges with the vast and unfamiliar scientific terminology. The conversation that follows portrays what they said.

*R: State the sections of genetic engineering that you found challenging.*
*L14: There is no specific part, but the terminology used was tough.*
*L33: The terms used were many and not common since we do not use them regularly.*

The above responses indicate that the long scientific names and language used in genetic engineering caused misconceptions because learners were unfamiliar with the biological technical terms. Unfamiliar biological terminology proved to be challenging even during classroom observations. During the lesson, some learners looked perplexed as the terms were being introduced one after another. Then the teacher asked:

*T: You look surprised, what is the matter?*
*L 2: Do we really have to learn these things or are they for tertiary learners?*
*T: yes, why?*
*L 2: These things are new, many and difficult.*

When asked to express his opinion about genetic engineering, the teacher reiterated that:

*The abstract and vast terminology used in this subtopic is challenging to learners and teachers alike. It challenges the teacher on how to help learners to conceptualise it- (T).*

The above responses from the learners and the teacher are an indication that abstract and unfamiliar biological terminology can indeed hinder meaningful learning. As Etobro and Banjoko, (2017) and Fauzi & Mitalistiani, (2018) observed, some terms like gene, DNA, genotype are foreign and add to the abstraction of the topic, thereby inhibiting construction of knowledge and meaning (Piaget (1967) in Ahmed et al., 2018). The struggle with the terminology eventually culminates in misconceptions.

***Lack of teaching/learning resources***

In an interview, learners were asked what could have been done differently to help them understand genetic engineering better. They responded thus:

*L 2: I think watching an internet video would have clarified what we learned.*
*L 17: Experimenting the whole process could have helped.*

The above responses suggest that for learners to have fully comprehended genetic engineering, they needed the use of some audio visuals or experiments. The teacher mentioned the same challenge in his response to what difficulties he encountered during his teaching of the subtopic. He said:

*T: Lack of teaching aids for demonstration of the processes caused the mentioned challenges because even the flow-chart on the handout given to learners could still not assist them to visualise these processes and steps.*

Although some learners advocated the use of practical work in genetic engineering, the school did not have appropriate facilities, resulting in misconceptions. Visual aids, such as diagrams of DNA structure, 3D animations, infographics, charts, and illustrations, are essential for explaining complex concepts. Textbooks that lack these aids can make it difficult for learners to grasp genetic engineering principles. Similarly, Bonde et al. (2014) asserted that insufficient laboratory apparatus and equipment, and lack of computer programs hinder development of conceptual understanding. By incorporating visual aids in teaching, teachers can create a more interactive and engaging learning experience, thereby helping learners grasp complex genetic engineering concepts more effectively.

***Inadequate content in learners' biology textbooks***

During the lesson, learners were asked:

*T: What is a plasmid?*
*L 14: A plasmid is a small circle of DNA in a harmless bacterium.*
*T: Okay, you have an idea but next time define it as a circular strand of DNA capable of self-replicating independently of the main DNA.*

The learner's response above came from their textbook. It falls short of the technical meaning of plasmid, reflecting content gap and highlighting the linguistic meaning based on the shape of the plasmid. This finding aligns with what Osman et al. (2016) found in their study that science textbooks did not reveal the essence of the subject and that they had unclear diagrams, resulting in misconceptions. Many textbooks provide an overview of genetic engineering concepts without delving into the details. This can leave learners with a superficial understanding, leading to misconceptions about genetic engineering concepts. Science is constantly evolving, and textbooks that are not regularly updated may contain outdated information. This can lead to misunderstandings about current practices and technologies in genetic engineering.

Another misconception that emanated from their textbook is a conceptual misunderstanding pertaining to transformation. The textbook defined transformation as "re-insertion" of the recombinant DNA into the bacterium. The use of the term "re-insertion" which is a process word in genetic engineering led many learners to confuse the process of transformation with the process of insertion. Evidence in this case is drawn from the interviews and post-test, where some learners explained insertion as *combining the cut gene with the cut plasmid and putting it back into the bacteria (*L 23*).*

The first part of learner 23's response correctly defined insertion. But the second part "*putting it back into the bacteria*" defined transformation, an indication of conceptual misunderstanding. It can also be deduced that the teacher's choice of the word "re-insertion" when referring to transformation might have also been influenced by the textbook.

***Teacher's incompetence with the content***

During a discussion between learners and their teacher, the teacher explained:

> *T: That bacterial cell before it was altered never had any ability to produce insulin. Now that you are reintroducing the recombinant DNA, this bacterium is going to have the ability to produce human insulin. So, what in essence have you done to this bacterial cell?*
> *L 12: We have altered it.*
> *T: The other word for altering is….*
> *L 7: We have transformed it.*
> *T: We have transformed it, hence the genetic process, transformation.*

The emphasis on only the change aspect of the transformation process by the teacher, led learners into focusing on the resultant part of the process-changing or modifying of the bacterial cell, thereby ignoring the other detail of the process which is the addition of recombinant DNA. Learners therefore focused on what recombinant DNA does to the bacterial cell leaving out the essential detail on how recombinant DNA got into the bacterial cell to change or transform its genetic capabilities.

The following are examples of definitions learners gave in the post-test:

> *L 6: Transformation is the process whereby an organism is changed into performing a new role.*
> *L 7: Transformation is the process in which a gene that was inserted into an organism changes the behaviour or features of that organism.*

Another incident where the teacher became a source of misconception was when he said the following after his explanation of insertion:

> *T: The recombinant DNA is then re-inserted into the bacterial cell.*

This suggested to the learners that transformation is re-insertion of recombinant DNA into a bacterial cell creating confusion between transformation and another process insertion. Learners interpreted the statement to be part of an explanation for insertion. As a result, some of them explained insertion as such in the post-test: For example:

> *L 17: Insertion means taking the cut-out target gene then placing it in a vector and the vector back into the bacterium.*

The teacher's use of the word re-insertion to explain transformation which led to learners' misconception alludes to the teacher's incompetence in the content he was teaching and seemingly unaware of this incompetence. He reproduced the text-book definition word for word while he should have corrected the use of the process word insertion to explain a different process transformation.

According to Alanazi (2023), teachers' incompetence in the content leads to misconceptions as the case was in this study.

To sum up, it can be concluded that the teacher unwittingly caused misconceptions in learners by using words, which though correct, either generated misconceptions since they were process words, or they only depicted part of the process in genetic engineering.

***Use of Ineffective teaching Strategies***

During an interview with the teacher, he was asked what he could have done differently if he was given a chance to teach the subtopic again and he responded as follows:

> *T: If we had more time, maybe I could have shown them a video clip to help them construct mental pictures of how the processes are carried out. But since we lost a lot of time due to the corona virus lock down, I have to hurry through the syllabus to ensure that we cover everything before they sit for their final examinations.*

The teacher's comment implies that due to his rush to cover the syllabus given the little time they had, he settled for an ineffective method of teaching, interactive lecture and failed to identify and use relevant visual aids or videos to help learners grasp what was being taught. The use of the interactive lecture approach was not so effective in concretising concepts in learners, hence leading to limitations in conceptual understanding (Bonde et al., 2014). Interactive teaching strategies, such as quizzes, simulations, and hands-on activities, can enhance understanding. If the teacher does not use such strategies, he may fail to engage learners effectively, resulting in persistent misconceptions.

To sum up, this section unveiled the following as possible causes of learners' misconceptions: vast and unfamiliar scientific terminology, lack of teaching/learning resources inadequate content in learners' biology textbooks, the teacher's incompetence with the content in genetic engineering and use of ineffective instructional strategies.

## CONCLUSION

The study found the most common misconceptions among learners related to processes associated with genetic engineering, genetic engineering as leading to formation of new species and it being a process that occurs only in micro-organisms. In addition, learners had misconceptions relating to the gene concept, and DNA concept. They also exhibited language misconceptions pertaining to the process of isolation in genetic engineering. Regarding possible causes of learners' misconceptions, the study revealed that abstract concepts and unfamiliar scientific terminology led to misconceptions in the teaching and learning of genetic engineering. It highlighted lack of teaching and learning resources to help learners concretise concepts, as leading to misconceptions. The learners' and teacher's use of inadequate textbooks was another cause of misconceptions. In addition, the teacher's poor mastery of the content and his choice of ineffective teaching methods contributed to the development of misconceptions in learners.

## Limitations

The study was limited in that it used convenience sampling in which one class of grade 12 learners from one school participated. This sample was convenient to the researcher since it was easily accessible. However, the selected sample is not representative of the entire high school biology learners in Lesotho. Therefore, the identified misconceptions cannot be generalised because they may be unique to the sample. Involving a larger sample of other schools or replicating the study in other regions could give a more comprehensive data, thereby increasing the generalizability of the findings. Furthermore, only one teacher was involved in the study. He used interactive lecture method of teaching. This could mean that the challenges he encountered are not consistent with other biology teachers' challenges who could have used different methods of teaching. Involving other biology teachers would generate more comprehensive data that could give a clearer picture of misconceptions in genetic engineering in the district.

## Recommendations

Based on the findings, the study recommends that the teacher training institutions in collaboration with the Ministry of Education and training offer some professional development opportunities for in-service teachers so that they continuously enrich their knowledge about genetic engineering and effective ways of teaching it. Another recommendation is that teachers should use resources such as simulations and videos to enhance meaningful learning of genetic engineering, hence foster conceptual change. In addition, the Ministry of Education and training through its panel that evaluates textbooks for suitability for high school biology leaners, should ensure that recommended books adequately cover the curriculum content and that their diagrams are clear and coherent with the content. Textbooks that do not integrate these perspectives can limit learners' holistic understanding of the topic. Since science is constantly evolving, and textbooks should be regularly updated. Without updating, this can lead to misunderstandings about current practices and technologies in genetic engineering.

## Areas for further research

Following up on this study, more research can be conducted on biology teachers' pedagogical content knowledge in genetic engineering. Another niche relates to the use of technologies in the teaching of genetic engineering.

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