ASSESSING VISUALISATION SKILLS OF MOLECULAR BIOLOGY FIRST YEAR STUDENTS IN A LANGUAGE DIVERSE LECTURE ROOM, SOUTH AFRICA

by

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DECLARATION

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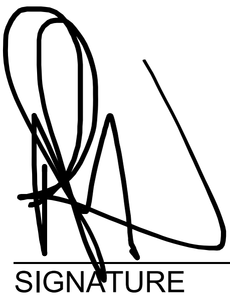
Assessing visualisation skills of molecular biology first year students in a language diverse lecture room, South Africa.

I declare that the above dissertation is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

I further declare that I submitted the dissertation to originality checking software and that it falls within the accepted requirements for originality.

I further declare that I have not previously submitted this work, or part of it, for examination at Unisa for another qualification or at any other higher education institution.



SIGNATURE

7/11/2020
DATE

DEDICATION

In loving memory of my father, my number one supporter, Papa Peter Matshediso Donald Mokhele: I know you still watch over me papa and I know you are still proud of me now, as you have always been.

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- To my Saviour, my Healer, my Provider, my Lord Jesus Christ. LORD, if it wasn't for your love for me, where would I be? You are the lamp upon my feet and a light for my path (Psalm 199:105), and today I am able to testify of your goodness and grace. Abba Father, you are worthy of all the praise.
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ABSTRACT

Students require visualisation skills to effectively interpret external representations of abstract scientific information. Despite the fact that the mother tongue of most science students is not English, the language has remained the standard medium of instruction at South African universities. Thus, the current study will explore the nature of visualisation skills that are required by university students in their first year of molecular biology. In addition, the current study will investigate the extent to which the mother tongue language affected how students interpreted external representations that represented mRNA translation. The study used an online-questionnaire and content analysis to collect data. Symbolic representation and the ability to retrieve information from memory were found to be the most frequently assessed nature of visualisation skills. Moreover, many students rejected the notion that learning molecular biology in one's mother tongue would enable them to effectively interpret external representations.

Keywords: Visualisation skills, Visual literacy, Science education, Molecular biology, Levels of abstraction, External Representations, Visual models, mRNA translation, Mother tongue language, Cognitive skills

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ABBREVIATIONS

COVID 19	Coronavirus diseases
CVM	Conceptualisation of visual models
ERs	External representations
EVM	Externalisation of visual models
IVM	Internalisation of visual models
VL	Visual literacy
VS/s	Visualisation skill/s

CHAPTER 1: INTRODUCTION

1.1 Background of study

The process of teaching involves improving the knowledge, skill and attitude of students (Meshram, Meshram & Raweker, 2017). However, both teaching and learning science can be complex. This is due to the complexity of the scientific content which may include abstract ideas, laws and theoretical entities (Wellington & Ireson, 2008). This is particularly relevant to the study of chemistry which involves the interpretation of changes that occur in matter. Understanding chemistry is based on the ability to explain chemical phenomena that can be observable at either a macroscopic or at a sub-microscopic level. Macroscopic changes include changes in the physical property of matter. These include changes in colour, odour or the formation of bubbles at the end of a chemical reaction. The fact that these chemical changes occur at the sub-microscopic level makes learning chemistry challenging or difficult (Cardellini, 2012). These sub-microscopic changes are usually represented in an abstract manner either qualitatively (such as the use of specialised notations or symbols) or quantitatively (by using equations or graphs) (Tasker & Dalto, 2006).

Presentation of ideas in a visual form has proven to be essential in science education (Dalacosta et al., 2009). For example, the use of animations to present both structures and processes at sub-microscopic level in chemistry has proven to be useful to educators. They are able to convey abstract, scientific concepts more visually to students (Falvo, 2008). The use of animations and video demonstrations in molecular biology assists students to improve their conceptual understanding of the three levels of representation i.e. macroscopic, sub-microscopic and symbolic (Velázquez-Marcano et al*.,* 2004). Therefore, according to Lai et al., (2009), the academic achievements and attitude of students' toward learning science has improved significantly through the use of animations in science. This is because these models are used to display data and organise complex information (Kozma, 2003). The models are also used to demonstrate the relationships between processes that would normally be difficult to describe (Cook, 2006).

Over the years, instructional methods which are used in science classrooms have diversified. In fact, verbal learning has always been at the forefront of education, while visual learning has lagged behind and is thought of as been redundant (Cook, 2006). However, language still remains as a critical component of communication, and as an important tool that allows students to understand complex and abstract scientific concepts (Adúriz-Bravo, Chion & Pujalte, 2013). Science is a practical subject but it has its own language which is known as scientific language. It appears that the scientific language is actually a specialised language with its unique set of rules, grammar and vocabulary (Matthiessen & Halliday, 2009). Scientific language often includes specialised vocabulary or scientific terms with specific meaning. It may often consist of words that is completely different to what students use in everyday language. Thus, it can be difficult to understand, especially by verbal explanation alone (Patrick, Carter & Wiebe, 2005). In consequence, scientific models have been created to enable students to access abstract ideas and make meaning from them (Gilbert, 2010). There are various types of scientific models and visual models which are important for the current study. Visual models have become critically important in science education, especially in providing a way to making invisible phenomena become a reality to students (Cook, 2006). Visual models have also been proven to improve students' ability to understand, evaluate and construct mental images of given information during the process of learning (Savec, Vrtacnik, Blejec and Gril, 2003).

Visual models can be represented in two ontological forms i.e. internal representations and external representations (ERs) (Gilbert, 2010). Internal representations represent personal, mental imagery construction which is also known as mental imagery. On the other hand, ERs represent the external images. The latter can be defined as visual and spatial displays that are used to promote discovery, memory, inference and calculation (Schonbörn & Anderson, 2006). ERs are also known as visualisation tools used in teaching and learning science. These include physical and molecular models, photographs, micrographs, pictures, diagrams, illustrations, drawings, images, analogical representation, metabolic maps, symbolic pathways, genomic representations, graphs, icons, static visuals, dynamic visuals, animated visuals, multimedia and virtual reality environments (Schonbörn & Anderson 2006).

Mnguni, Schönborn and Anderson (2016) investigated some of the cognitive skills needed for visualising ERs used in science education. The results of the study identified 24 cognitive skills which were associated with visualising ERs, and which they regarded as visualisation skills. Hence, this study exemplifies the need to identify visualisation skills (VSs) which are required by students to master science, along with identifying other factors that may affect students' ability to construct meaning from ERs. Such knowledge will assist educators to take meaningful action in assisting students to process ERs effectively.

1.2 Problem statement

The research problem in the current study focuses on the apparent lack of VSs among molecular biology students. According to Schonbörn and Anderson (2006), students find it challenging to master the abstract and diverse symbolic language used in molecular biology. It is quite evident that the use of ERs in science education can be beneficial for learning by making what is abstract and invisible become more mentally visual (Schonbörn & Anderson, 2006). According to Mnguni et al*.,* (2016), the need to develop VSs for better comprehension, communication and construction of knowledge in molecular biology is critically important. The same skills would also assist students to easily navigate within and between the different modes of ERs used in the curriculum (Gilbert, 2005). In science education, visuo-semiotic reasoning enables students to understand, evaluate and produce visual representations of the ERs used in science. In fact, visuo-semiotic reasoning is a critical component of the much needed VSs. Visuo-semiotic reasoning is essential in science education and should be part of the curriculum in secondary and higher education (Mnguni, 2019).

However, little research has been done to investigate whether science students particularly in the field of molecular biology possess the necessary VSs needed to correctly visualise, process and interpret the ERs used in the curriculum. Additionally, there remains a gap in literature with regards to the nature of VSs and visual literacy (VL) in science education (Mnguni, 2014). Also, there is no references to the quality of VSs that are required by 1st year university molecular biology students. For this reason, the current researcher believes that the lack of VSs among students (Schonbörn & Anderson, 2008; Grisham, Power & Riles, 2007) could hinder their ability to effectively learn through the use of ERs (Mnguni et al*.,* 2016).

Nevertheless, language still remains the key component for communication and understanding in the science classroom (Benson, 2004). According to Mammino (2010), language is an essential instrument for developing VL in science education. Mnguni (2014) defines VL as the ability to select and effectively use a set of cognitive skills for perceiving, processing and producing visual models which are critical in science education. VL is considered to be a form of a language itself. In fact, to teach VL in science education there needs to be shared scientific language between the educator and the students. ERs used in science education are actually considered as linguistic tools which are used to communicate scientific information.

Additionally, Mammino (2010) suggests that using one's own mother tongue makes for an excellent tool in assisting students with familiarizing themselves with the scientific language. Students are often faced with the challenge of not understanding the scientific language either with or without the use of ERs. Tan and Soong (2006) postulated that this kind of challenge is often experienced by students who are learning science in their second language, rather than in their own mother tongue.

In line with Mammino (2010), the current researcher postulates that learning science in a second language acts as a barrier. Countries like South Africa are characterized by diverse cultures and multilingualism; however, English continues to be the preferred language of instruction and learning in most of the educational systems. The use of English to deliver the science curriculum to the majority of the tertiary institutions within South Africa is hypothesized to be a contributing factor to students' lack of VSs among second language English speakers. Language remains a barrier for transferring scientific knowledge in the field of molecular biology and hinders students from learning effectively through the use of ERs (Amano González-Varo & Sutherland, 2016). By developing VSs in the mother tongue of students' would allow them to correctly visualise, process and interpret the ERs used in the curriculum (Mnguni, 2019).

1.3 Research questions

The following research questions emerged which are central to the current research:

1. What is the nature of VSs that is required by 1st year university students to effectively interpret ERs, particularly when learning about (messenger RNA) mRNA translation in the field of molecular biology?

2. To what extent does instruction in the mother tongue affect how students interpret ERs which are used in explaining mRNA translation?

1.4 Rationale

The detailed understanding of mRNA translation has become vital for molecular compounds and processes, and this has been made possible with the use of ERs. The justification for the current research is that often molecular biology instructors rely on the use of ERs when teaching about mRNA translation. Thus, it has become critical for instructional designers and educators to understand how students use and interpret ERs. Therefore, the current research could provide instructional designers and educators insight into the role of VL as a language of communication in molecular biology. This in turn could assist in the development of effective teaching strategies.

Based on research, VSs within the general population may vary among the various ethnic groups. The difference is believed to be because of students' prior experience and educational background (Ault & John, 2010). Students come to the classroom with a range of pre-existing knowledge and skills that they acquire through their year's education. In light of this, a large number of South African universities are composed of students of diverse languages. Based on studies conducted in South Africa, research shows that a large number of second language students tend to have challenges with regards to learning in English. This is due to the fact that students are not exposed to English in their homes. Also, they experience a lack of support from their parents as their parents are unable to understand or speak the English language. This means that students experience difficulty in comprehending the content knowledge of the subject, and as a result this adversely affects their academic performance (Desai, 2001). According to Hayakawa and Keysar (2018), using a foreign language may reduce the vividness of mental imagery due to reduced access to sensory memories which are the ingredients for novel mental representations. However, because the curriculum is only taught in English which may not be the native language of the majority of the molecular biology students in SA universities, the current researcher proposes that students be taught the curriculum in their mother tongue.

In line with Mnguni et al. (2016), assessing VSs among molecular biology students would mean that educators need to make necessary changes to the curriculum. They need to prioritise the development of the skills needed by students to process and construct meaning from ERs to ensure better comprehension, communication and construction of knowledge in molecular biology. Furthermore, Mnguni et al. (2016) suggests that educators need to be aware of the absence or presence of VSs among the students before choosing the type of ERs that could be appropriate to deliver the content information.

1.5 Aim and objectives

Given the need to help instructional designers and teachers to effectively use visual models in science education, the present aims of the study are:

1. To investigate the nature of VSs that are required by 1st year molecular biology students for effective learning through the use of ERs.
2. Also, to investigate the influence that teaching molecular biology in the mother tongue has on student learning.

The objectives of the present study are:

1. To investigate the nature of VSs that are required by 1st year molecular biology students to effectively process and interpret ERs when learning about mRNA translation.
2. To explore the extent to which the first language (mother tongue) affects how students interpret ERs used in explaining mRNA translation.

1.6 Addressing the research questions

To address the research questions presented above, the researcher will follow the process outlined (Figure 1.1).

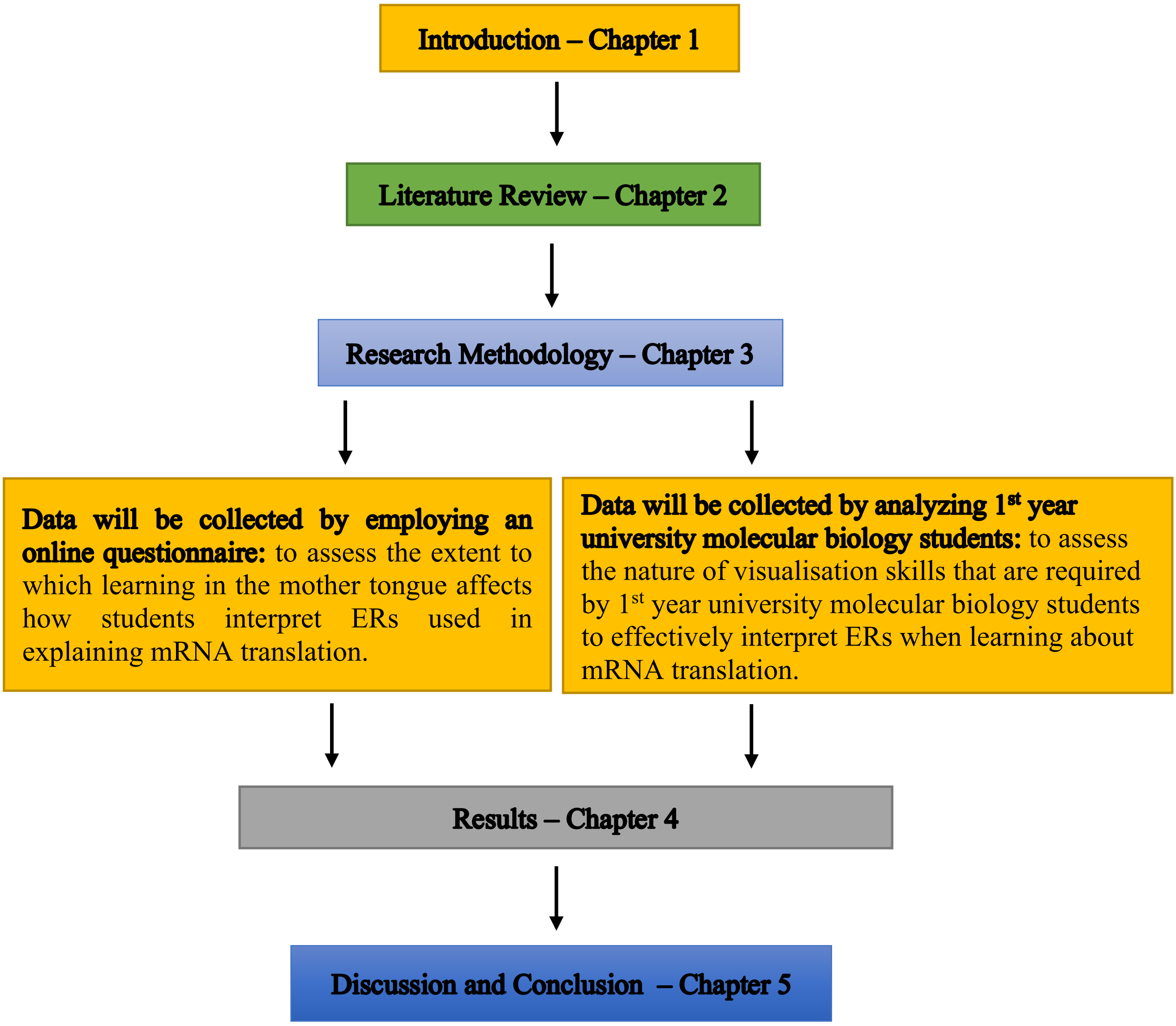


Figure 1.1: Thesis outline

Figure 1.1 presents the outline which will be followed. Chapter 1begins with introducing the research topic, research questions and research aims of the research study. Then followed by the literature review in Chapter 2. In Chapter 3, the research methodology will discuss how data will be collected using two different methods to answer the two research questions i.e. (1)

data will be collected by questionnaires to assess the extent to which the mother tongue affects how students interpret ERs that is used in explaining mRNA translation. (2) data will be collected by analysing assessments used to assess the nature of VSs required by 1st year molecular biology students to effectively interpret ERs used when learning about mRNA translation. Chapter 4 will present the results of the study and Chapter 5 will discuss the findings of the research and provide a conclusion.

1.7 Conclusion

It is quite evident that particularly in the discipline of molecular biology, there is a need to identify VSs that are required for students to process and construct meaning from ERs. By identifying these VSs, instructional designers and educators are able to better assist students to learn through the use of ERs, visualise the ERs and correctly interpret the ERs used in molecular biology. Additionally, developing students' VSs in their mother tongue would assist them to advance in their understanding of the scientific language used in the curriculum, therefore eliminating the use of English. This is significant because English is widely used as medium of instruction in many of the higher education institutions in South Africa. Thus, the current researcher deems that the use of English as the medium of instruction would hinder students from learning effectively through the use of ERs in molecular biology.

CHAPTER 2: LITERATURE REVIEW: THE IMPORTANCE OF VISUAL LITERACY IN SCIENCE EDUCATION

2.1 Introduction

Kedra and Zakeviciute (2019) related an intriguing anecdote about a five-year-old girl who was trying to explain to her mother what she did in gym class that day. Despite the young girl's best efforts to explain, her mother remained confused. The little girl was unable to fully express herself verbally to her mother. However, the young girl was relentless. She took a piece of paper, and with colouring pencils started to draw all the activities she did in gym class step by step, along with verbal explanations to indicate the movement of all the participants in the gym class. The visual illustration assisted the mother to understand what her daughter was trying to tell her, something that was not feasible by an oral explanation alone.

According to Kedra and Zakeviciute (2019), "the nature of today's communication is overwhelmingly visual" (p.1). Over the last decade, modern classrooms have moved from presenting the curriculum verbally to incorporating visual elements. The rise in the number of publications dealing with the use of images in the classroom indicates the interest of educators in transitioning from text to the visual world (Duchak, 2014). Nonetheless, it is quit alarming that the 21st century students who are known to be the visual generation are not visually literate (Duchak, 2014).

Even though today's students are born in a visual, image dominated world, the moment they enter higher education, "they are thrown into an almost completely textual world" (Kedra & Zakeviciute, 2019, p.1). Hence, as much as the contemporary and post millennial generation are technologically savvy, research shows that a large percentage of science students are visually illiterate (Kedra & Zakeviciute, 2019). This means that they don't know how to effectively interpret ERs for effective communication (Brumberger, 2011).

According to Mnguni, 2014, VL is one of the most crucial forms of literacies, especially for molecular biology students who are taught complex phenomena that include concepts such as DNA replication and mRNA translation. These two processes exist at a microscopic level and cannot be visualised. According to Vekiri (2002), ERs allow one to process information more efficiently. This means that the use of visuals in teaching and learning results in a greater degree of learning. Since education has to compete with this visual word, all types of teaching material from traditional text books to the latest educational technological resources should contain diverse, pictorial representations. Hence, over the years the presence of ERs in textbooks have been increasing.

VL is a very broad concept with various definitions. According to Ametller and Pinto (2002), the concept of VL in science education encompasses the ability to read (making sense of what is read), ability to write (drawing) ERs, and the ability to learn (think) and express oneself in terms of images. This involves the use of a range of skills from simply identifying what is observed to a more complex step of interpreting what is being observed on a more contextual, metaphoric and philosophical level. Just like a child is taught how to read and write, skills such as the ability to interpret observed visuals should be explicitly taught to the students in order to assist students to access the curriculum with ease.

How effective are ERs in the classroom? In a study done by Mayer et al. (1996), the researcher compared the use of a multimedia summary with a text only summary of a certain process. The multimedia summary comprised of an annotated illustration, depicting the steps in the process. The text only summary consisted of 600 words that described the process. The researchers also compared the use of multimedia summaries with different amounts of text. The results showed that the multimedia summary was more effective than the text only summary. Similarly, the multimedia summary with the least amount of text was more effective than the summary which contained a large amount of text. Therefore, constructing meaning from science texts not only relies on the words used in the text, but also relies on the visuals which accompany the text.

Regardless of how effective ERs are in the classroom, science students often face challenges in comprehending them. Lowe (2000) states that educators often assume that the images which are used in the curriculum are self-explanatory. This assumption is supported by the extensive research in science education which has revealed that a huge discrepancy exists between educators and students' in their ability to interpret and comprehend ERs. This is due to the reason that educators tend to have a greater conceptual knowledge on the subject matter than students do. They assume that students are as visually literate as they are. This assumption is based on the thought that students should have automatically acquired the skills required to visually interpret and understand ERs during the course of their learning. However, Seufert (2003) claims that this assumption is not fair on the students. If the skills are not being explicitly taught to them through specialised designed activities, many students do not improve their VSs.

However, a study was conducted to understand the students' confusion with common science diagrams and their misinterpretation of ERs that were used in the science curriculum (McTigue & Flowers, 2011). Often students are skilled at reading texts and making sense of the text; however, they do not know how to apply the same skills when comprehending the diagrams. The study (McTigue & Flowers, 2011) reported that as science educators, we often teach our students by using the text which accompanies the graphics, and the vocabulary that goes along with it. We often neglect to explicitly explain what the images mean, even in the absence of text.

The misinterpretation of the science diagrams by students can be explained with an example. For example, students perceive the arrows in Figure 2.1 to always be pointing out the item of interest. This is true according to what they have been previously taught. However, failing to grasp the main idea which is the direction of the exchange of gases (oxygen given off by the leaves and carbon dioxide taken in by the leaves), and how the water moves from the soil and gets absorbed by the root is often misinterpreted by students. This leads to the question on whether students are able to understand the purpose of diagrams in the science curriculum. With that being said, students should be given opportunities to engage with a number of science diagrams which are relevant to the subject/topic and level. This will assist students to be familiar with the ERs which are used in their curriculum, and thus avoid misinterpretations.

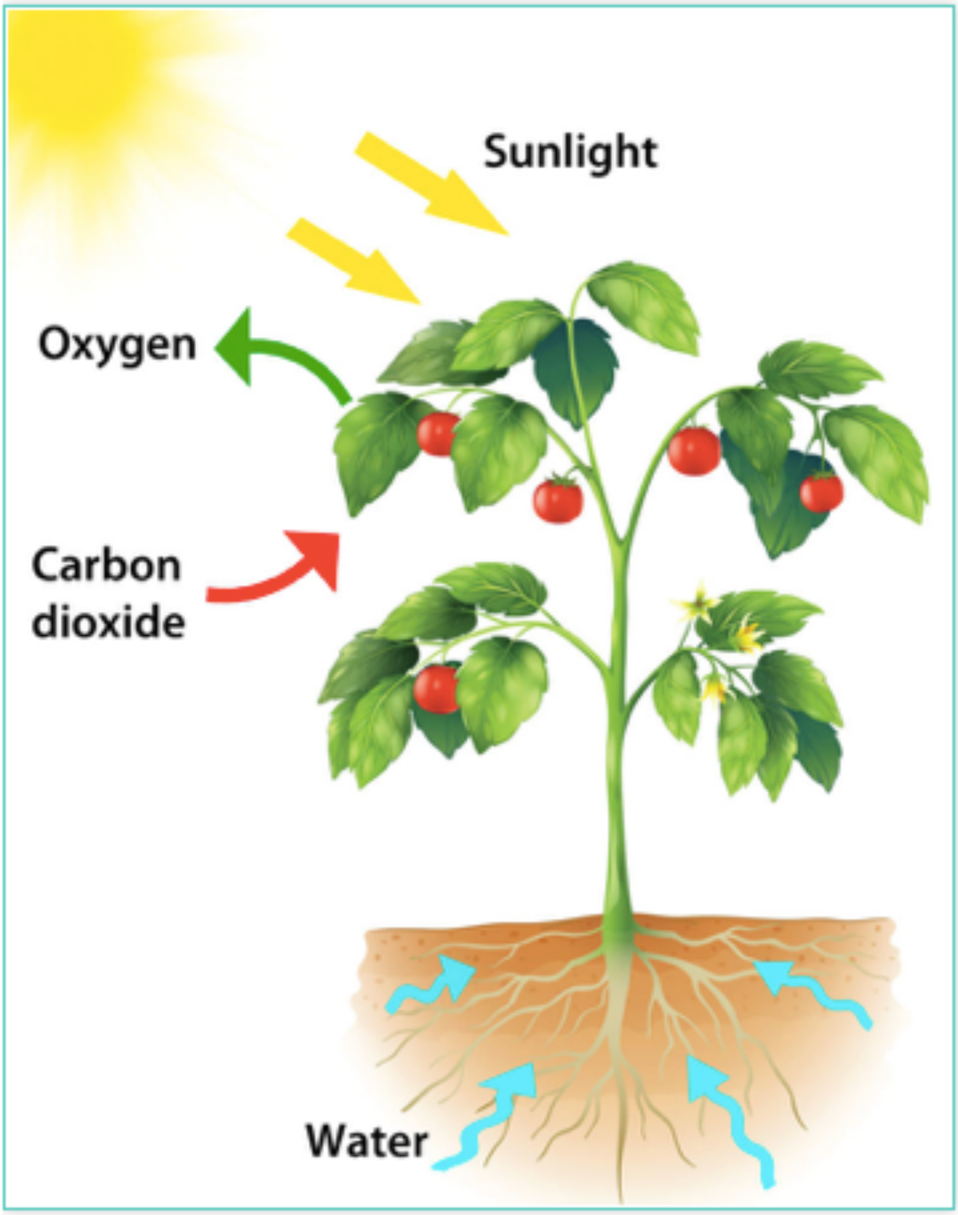


Figure 2.1: Illustration of the process of photosynthesis for grade six students. Retrieved from https://photosynthesiseducation .com/photosynthesis-for-kids.

Another study done by Schönborn (2005) also exposed student's visualisation difficulties of ERs used in biochemistry. The study focused on the students' interpretation of ERs by depicting antibody-antigen binding. The one example included a black line which was used to denote an -S-S- bond that was interpreted as a hydrogen bond. On the other hand, graphical amino acid regions were perceived as atoms and cells. It is clear that students are still not visually literate, even after increased exposure to ERs in the past. Students will continue to be visually illiterate if we continue to expose students to ERs without teaching them how to correctly interpret the visuals.

In science, the comprehension of specialized, scientific images require specialised skills far beyond the everyday skill of visualizing pictures in a magazine or story book. According to Duchak (2014), in order for students to correctly interpret ERs, it is the educator's responsibility to develop the student's capability. There are various ways in which teachers can support their students with regards to being visually literate. For example, students' VL skills can be developed by educators guiding their students on how to develop their own diagrams of simple concepts or processes.

According to Stokes (2002), students often learn best visually. Furthermore, Schönborn and Anderson (2008) postulated three reasons as to why VL should be explicitly taught as part of the modern biochemistry curriculum. Firstly, the more students are exposed to diverse and potentially confusing ERs during the course of their studies, the more they will require even greater levels of VL. Secondly, for students to effectively interpret and comprehend ERs which are used in the curriculum, it will be required for students to develop their own VSs far beyond what they would normally acquire informally. Thirdly, students with poor VL show evidence of poor VSs which affects their ability to interpret and comprehend the ERs used in the curriculum. Therefore, being visually literate should actually be a prerequisite in science education, as ERs are becoming an integral part of how information is presented in the 21st century.

With the proposition of making ERs as an integral part of science education, there clearly needs to be a shift on how learners are taught science and mathematics. In mathematics, there needs to be a shift from the concept of "watching" mathematics, to a more innovative way of conveying knowledge, where students rather "do" mathematics through interactive activities. As noted by Schönborn and Anderson (2008), one contributing factor to students' misinterpretation of ERs is that students are not explicitly taught the skill to correctly visualise graphics and other images as part of the science curriculum. To avoid misinterpretation of ERs, the skills that are needed to correctly visualise and interpret ERs should be taught to students and they should be given opportunities to practise the skills.

Lastly, the development of VL in science education is supported by Zull (2002) who states that educators should be making extensive use of ERs in their lessons to assist students to better understand the content. This can be done by teaching students by using visual images or by simply just asking students to represent their knowledge in a visual form. Wieman (2007) supports this perception and argues that a range of ERs such as simulations need to be included in every lesson, particularly in science education. Therefore, Handelsman, Miller and Pfund (2007) further states that with educators using "visual frameworks" in their lessons, this will not only assist students to better understand the science content, but to also to think scientifically.

2.2 Characterising ERs used in molecular biology

According to Offerdahl, Arneson and Byrne (2017), student assessments which are both "formative and summative not only communicate to students what is expected of them in terms of performance, but also send an implicit message about the nature of knowledge i.e. the VSs required in the discipline" (p.3). For example, if 1st year molecular biology students' assessments do not contain any ERs, this can imply that educators do not value VL. In this regard, Airey and Linder (2009) stipulate that assessments must be used as tools to reinforce the importance of VL used in the textbooks, and not just to assess students' knowledge.

Molecular biology textbooks frequently make use of discipline-specific graphical and diagrammatic features, varied levels of abstraction and special arrangements of visual elements to present information (Schönborn and Anderson, 2006). The levels of abstraction used in representing information can often be problematic for students, more especially when trying to interpret ERs (Schönborn & Anderson, 2010). Having said that, Offerdahl et al. (2017) proposes variation in abstractions, of which the researcher describes variation in abstraction as "a continuum ranging from more detailed and realistic representations on one end to representations that are less detailed and more abstract then the other" (p.4). This suggests that variation in abstraction is necessary as it reduces students' cognitive load. This is significant as molecular biology students often "do not possess the familiarity needed to recognise relationships between representational (e.g. ribbon) and conceptual (e.g. secondary protein structure) elements which require that they spend more cognitive capacity on processing information" (p.5).

In light of the above discussion, Offerdahl et al. (2017) developed a taxonomy for the various abstractions. This taxonomy allows for characterising ERs into five general categories of abstraction used in biochemistry and molecular biology as seen in Figure 2.2. The characterisation of ERs supports the development of VL. This reduces the pressure of having to handle multiple representations at once and thus creates instructional opportunities for students to deal with one characteristic of representations individually. This is one of the ways in which educators can assist students to effectively interpret the ERs that are used in the curriculum and which is needed to improve their VSs.

The first level of abstraction that is commonly used in biochemistry and molecular biology is the *symbolic* representation. Symbolic representations are the type of representations in which a letter, word or a phrase is the sole representation of a structure, concept or process. The majority of figures which are coded as *symbolic,* use abbreviations, names, or symbols to encode information (e.g., amino acids represented by chemical structures, chemical formulae, one-or-three-letter abbreviations, or their names).

On the other hand, *schematic* representations are the type of ERs that involve the use of lines, arrows, and/or other abstract, pictorial elements. Schematic representations depict complex ideas. They omit superfluous elements and contain only minimal features that are needed to convey or interpret the message. Chemical reactions and metabolic processes are frequently represented as schematic representations in biochemistry and biology. Chemical structures are also considered schematic representations, as atoms and bonds are signified by abbreviations and lines, respectively.

The third type of ER are the *Graphs.* Graphs are often represented as curves, bars, plotted points to depict a relationship between two or more variables.

Conversely, *cartoons* are ERs that typically include more visual detail than the previous categories. This category includes nonconventional cartoons (e.g. artist renderings) and conventional cartoons, which are usually used by biochemists to represent molecules (e.g. ribbon diagrams), which possess their own visual shorthand for decoding and interpretation.

Lastly, *realistic images* are the other type of levels of abstraction in which an object's likeness has been captured on film and therefore include the most visual detail. Generally, these are limited to photographs and electron micrographs. While realistic images are arguably the most realistic representations, and are short of interacting with the actual subject of the image, they can still depict more abstract information. For instance, photographs of electrophoretic gel might need to be interpreted.

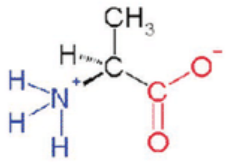
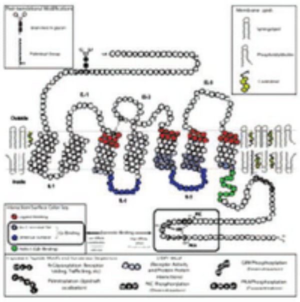
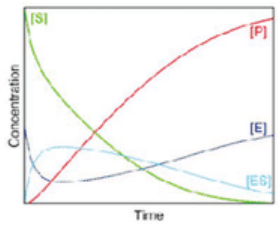
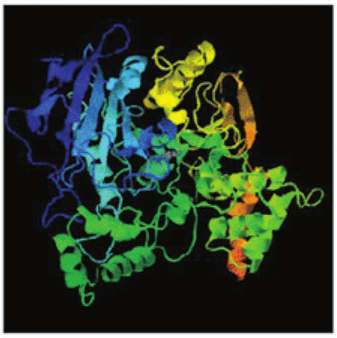
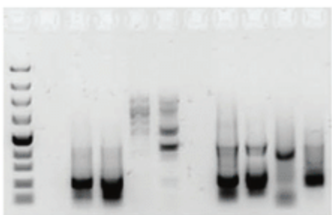
Type of Abstraction		Description	Examples
Symbolic (SYM)		Representation that expresses information using abbreviations, formula, names, or labels, which require translation.	amino acid abbreviations, chemical formula, mathematical equations
Schematic (SCH)		Diagram that uses abstract symbols (lines, arrows, etc.) to represent elements of a system, and often omits details to simplify information it intends to convey.	chemical reactions, metabolic processes, phylogenetic trees, pedigrees, molecular maps
Graph (GRA)		Depiction of relationships between data sets using a series of dots, lines, etc. that are often plotted with reference to a set of axes.	titration curves, Ramachandran plots, reaction coordinates, Lineweaver-Burk plots
Cartoon (CAR)		A drawing or computer-generated image that simplifies or emphasizes particular features or properties.	ball-and-stick models, space-filling diagrams, ribbon diagrams, artist renderings
Realistic (REA)		Representation that closely resembles the original subject, which may contain superfluous contextual information.	electrophoresis gels, electron micrographs, photographs

Figure 2.2: The characterisation scheme for abstraction in biochemical and molecular biology representations (Offerdahl et al., 2017).

2.3 Guidelines for teaching VL in science education

According to Felten (2008), schools have often focused on using words and text as the source of knowledge, even though students continue to struggle to visualise complex biological processes in molecular and cellular biology. Kedra and Zakeviciute (2019) suggests that institutes of higher education should truly take advantage of introducing VL education across the different fields of science (Bleed, 2005; Felten, 2008). However, the major challenge in doing so is knowing how VL can be explicitly taught to students. Furthermore, knowing how to effectively use ERs in the science classroom is another challenge that needs to be looked at.

Based on Schönborn (2005), the researcher identified 10 fundamental guidelines for teaching and learning with ERs in molecular biology education:

The first essential guideline in teaching and learning with ERs in molecular biology, involves *taking cognizance of current theories of how individuals learn from and visualise ERs*. This guideline is based on the theory of constructivism. Constructivism is known to be one of the most dominant theories that various researchers use to explain how students learn science. Constructivism is based on the principal that knowledge and ERs cannot be transferred from the educator to the students' brain by "osmosis." On the contrary, students learn science by constructing their own meaning and mental pictures (Johnson-Laird, 1983) This is based on their prior knowledge on what the student already knows on the subject matter. Another theory thought to explain how visualisation can be improved among science students is the dual-coding theory.

The dual-coding theory is based on the notion that the brain constructs mental, visual models from the connection of both verbal and visual representation. According to Schönborn (2005), visualisation of ERs can be improved when the connection between verbal and ERs is promoted. But how can the connection between the verbal and ERs along with what the student knows already be promoted? The answer is based on Mayer's theory which is founded on four simple principles. Firstly, the multimedia effect suggests that for deeper learning to takes place, verbal (spoken or text) and ERs should be presented in combination rather than being placed in isolation. Secondly, coherence effect suggests that effective learning takes place when irrelevant information is removed from the activity presented. Thirdly, the spatial contiguity effect suggests that learning is improved when words are placed in close proximity to the pictures, rather than in isolation. Fourthly, the personalization effect suggests that students create better mental images when the accompanying text is presented in a conventional manner (Mayer, 2003).

Addressing the key factors affecting students' ability to visualise ERs is another guideline that is deemed important in teaching and learning with ERs in molecular biology. Based on the study done by Schönborn and Anderson (2004), six factors have been identified that determine the student's ability to visualize and interpret ERs in biochemistry which could also apply to molecular biology. The factors include: 1) students general reasoning skill to interpret ERs used in molecular biology; 2) students ability to read and make sense of ERs used and their features; 3) students' ability to select and retrieve that which is relevant to the ER used; 4) students understanding (or lack of) of the subject matter relevant to the ER; 5) the nature, mode and quality of the ER used; 6) the nature and extent of which the students are able to select a representation by the ER and its symbolism. According to Schönborn and Anderson (2006), the above-mentioned factors are indeed required for sound visualisation of ERs to be used in molecular biology. To improve on students' VL, the researchers propose that each of the above motioned factors should be addressed. Factors 1- 4 could be addressed with the use of various learning activities which are integrated in the curriculum, focusing on enhancing the conceptual knowledge, reasoning skills (Hill, 1988) and VSs. On the other hand, factors 5 and 6 could be addressed by encouraging curriculum designers to integrate ERs into the curriculum (Schönborn & Anderson, 2006).

The third guideline involves *acknowledging the importance of pedagogical content knowledge in visualisation.* Schönborn and Anderson (2006) suggests that when thinking of strategies to improve on student's VSs, it is highly imperative to acknowledge the importance of pedagogical content knowledge. Based on the same literature, the researcher deems that the pedagogical content knowledge not only includes factual knowledge of the subject, but how the content knowledge is to be taught to the students. Pedagogical content knowledge is based on the principle that as educators, our chosen method on teaching a particular concept is dependent on the nature of the concept. For example, the methods used in teaching genetic coding would undoubtedly be completely different to the methods used in teaching Michaelis-Menten kinetics. With regards to the ERs used in the curriculum, acknowledging pedagogical content knowledge when designing the curriculum along with learning and teaching activities would mean curriculum designers are aware of the nature of students' and educators' conceptual reasoning and their level of VL. The reason being is that each conceptual reasoning induced by certain ERs would require a different approach to teach than other ERs used in the curriculum. Applying this reason when designing the course curriculum can improve the VL of the students (Schönborn & Anderson, 2006).

Making sure that the message depicted by ERs is explicit to students is the fourth guideline. Schönborn (2005) believes that when using ERs in a molecular biology lessons, it is highly imperative that educators explain to students what is the purpose of the ER, how is it tied up to the content topic (Lowe, 2003), and what is implied by the ER (Henderson, 1999).

The fifth guideline requires that teachers *ensure that students' have knowledge of the visual language and conventions used by ERs.* Schönborn and Anderson (2006) report that just like written language, the visual language contained in ERs consist of symbolism. Symbolism is when symbols are used to represent ideas or information. Ametller and Pinto (2002) postulates that symbolism needs to be explicitly taught to students in order for them to gain the necessary visual language used in molecular biology which in turn would improve their VL.

Making students aware of the limitations of each ER is the sixth fundamental guideline. In science education, it is important that both students and educators are constantly aware of the limitations of each ER. They should not always focus on what is represented by the ER, but also determine what is not represented by the ER (Schönborn, 2005). According to Henderson (1999), determining limitations of ERs can be done by consciously analysing, scrutinizing, critiquing and discussing each ER used in the course. This can help to improve a student's VL.

Fostering a multiple representation approach to the visualisation of ERs is the seventh guideline. According to Schönborn (2005), a students' ability to interpret and translate between a range of ERs builds powerful and integrated mental models of biochemical phenomena. In addition, this enables students to develop an array of cognitive strategies to allow them to effectively interpret ERs. Various literature builds upon the notion that science students should be exposed to a wide range of ERs of the same phenomena, thus merging a variety of mental models into one realistic model to improve their VL. This type of thinking would be appropriate in a biochemistry lesson, focusing on the different types of protein structures (Schönborn & Anderson, 2006), and by giving students activities that require them to identify different ERs of the same protein. This will enable students to critically analyse different ERs and build more realistic mental images of the protein.

The eighth guideline is to *empower students with the necessary skills to process biochemical ERs.* Research shows that little attention has been directed on explicitly teaching VL to molecular biology students. Another way of developing a student's VS sand VL is by exposing students to a wide range of tasks containing ERs. For example, interpreting an ER which depicts a quaternary protein structure would require 3D VSs, while ERs depicting a genomic map would require a skill for reading genomic base sequences (Schönborn & Anderson, 2006). Furthermore, Schönborn and Anderson (2006) suggests that it is important that students develop their own transfer skills which would enable them to link and transfer between ERs of the same phenomena, but in different contexts (e.g. between chemistry and biology). In consequence, making their knowledge more flexible (Grayson, 1995).

The ninth guideline depicts that teachers *develop students' metacognitive processing skills.* As stated by Ametller and Pinto (2002), in science education it is important to give students activities that stimulate their metacognitive skills. This is essential to ensure that students are thinking about their thinking during their learning process while being exposed to activities involving ERs. By students reflecting on their own interpretation of ERs, this improves on the student's VL which will enable them to construct more powerful mental images and more meaning (Pieza & Voxman, 1997). According to Schönborn and Anderson (2006), there are many ways in developing students' metacognitive skills. One way of doing so is by encouraging students to either take a step back and constantly assess their own understanding of the ER or to determine whether they are correctly interpreting the symbolism in the ER. Additionally, by students constantly assessing their own learning and understanding of the ERs, this will also enable the students to assess whether the ER used is a good representation of the phenomena or whether it is misleading. Students' ability to think about their own thinking during the process of learning enables students to become better metacognitive thinkers (Schönborn & Anderson, 2006).

Lastly, *using learner generated ERs to help students visualise biochemical phenomena.* According to Gobert and Clement (1999), having students generate their own diagrams of cellular and molecular structures can enhance students' VL. By assisting students to construct and refine their own ERs can help to improve student's ability to process abstract ERs (Lowe, 1991).

Therefore, according to Kedra and Zakeviciute (2019) implementation of the above-mentioned guidelines can be quite demanding. This is why the guidelines should be introduced in a systematic way, rather than focusing on introducing all of the guidelines at once. Kedra and Zakeviciute (2019) advocate that VL education requires "revolutionary thinking, assessing, grading and testing" (p.5). The researchers deem that VL education is actually quite complex, it is "ephemeral, momentary, multitasking, simultaneous, random, non-structural, it happens digitally" (p.5). It happens traditionally, switching between digital and non-digital learning platforms. Nonetheless, all this is attainable in one classroom.

In light of the about guidelines, it is clearly evident how important VL is in science education. VL can assist educators to be able to discuss abstract concepts that would not easily be explained to students verbally. Moreover, the use of ERs in the science classrooms is believed to be a major strategy in making what is invisible to the human eye more perceptible to students. All the more reason why substantial research needs to be done in the area of VL. The challenge with VL education is that it requires highly skilled and visually literate educators or instructors. Hence, there is a need to train educators in order for them to provide students with new transferable, visual skills.

2.4 Linking cognitive psychology to how knowledge is represented in science education

According to Gilbert (2005), visualisation refers to either how an object is perceived or can refer to the mental picture that is formed once the object is perceived. Literature indicates that visualisation in science education draws on the insight from cognitive psychology, science and education (Beatty, 2013). Subsequently, with cognitive psychology referring to the study of how people perceive, learn, remember and think about information (Sternberg & Sternberg, 2012), it can be postulated that cognitive psychology can be useful in explaining how students visualise ERs that are presented in the science curriculum. Therefore, by understanding how students visualise ERs, educators will be able to support students better in developing their VL skills and this can result in improved performance in science.

Nonetheless, when it comes to perceiving presented information, how does it really happen? Felten, (2008) considers seeing to not just being a passive process of just receiving a stimulus thorough our eyes, but also a process involving the brain to make meaning of what you are seeing.

With regards to visual perception, the external stimuli would enter our eyes and get projected on the retina which is situated at the back of the eye. Typically, a person views a 2D line drawing of a cube as 3D. This happens because our eyes project depth on to the flat surface of the cube, thus assembling similar shapes to the similar 2D drawing on the sheet to form a 3D cube (Felten, 2008). Visual perception is not only based on the external stimuli that enters our eyes, but on other aspects such as the viewpoint that an individual has toward an object. This is the reason why people would see the same object differently as no two viewpoints are alike.

Additionally, Bilbokaitė (2008) deems that human perception is selective as the brain would only select what it believes to be important and ignore what is not necessary, thus protecting the conscious mind from an overload. According to Bilbokaitė (2008), during a biology lesson on the internal organ system using an audio-visual presentation, the student would only perceive the essential details of the internal organ system, while processing the images and producing mental VSs of the system. On the other hand, if the information was to be presented by verbal expressions alone, the students would find it very difficult to perceive the information, process it and form mental images. This is because the human brain would only select verbal expressions which would not have any visual analogues accompanying it.

Nonetheless**,** how do we perceive objects as they are? Two theories are used to explain, how we see things around us:

Bottom - up theories: These theories use the notion that perception starts as soon as the stimuli enters the eye while viewing the object. This type of perception is stimuli driven (Sternberg and Sternberg, 2009).

Top - down theories: According to Clark (2003), these theories are formulated on the notion the that perception is driven by high-level cognitive processes, prior knowledge and experience.

One of the bottom-up theories is referred to as depth perception. Depth perception is deemed as the ability to distinguish distance between two objects. Mnguni et al. (2016) identified 24 VSs (Table 2.2) among biochemistry students from a South African university. 'Depth perception' was one of the VSs required to understand visual images used in biochemistry. This enables one to perceive the world in 3D and the ability to judge the distance between objects. The study showed that ERs that required the use of the 'depth perception' were not fully comprehended by students who lacked this VS.

The possible reason to the lack of 'depth perception' skill would be that this type of perception not only relies on visual cues, but also relies on prior knowledge and experience (Sternberg & Sternberg, 2009). For example, if one is knowledgeable about the size of an object from previous experience, the brain is able to estimate the distance between the reference surface and the object. Therefore, if a person has no prior experience or engagement with the object, they would struggle to estimate the distance between the reference surface and object due to having no frame of reference.

So, what are visual cues? Depth perception is demonstrated by visual cues which assist us in understanding some of the visual information that goes through our eyes. Depth cues are either monocular/pictorial or binocular. Monocular cues simply mean that the information gets taken through one eye to reach the retina. Two of the common monocular cues include factors such as relative size and interposition. Binocular cues mean that the information would go through both eyes to reach the retina. Convergence and retina disparity are some of the examples of binocular cues that we use to make sense of the visual information that go through our eyes. Monocular cues that are used in the science curriculum improve our brains ability to convert 2D information into 3D for better understanding (Sharma & Kumari 2017). Without depth perception cues, it would be difficult to illustrate some the of the abstract concepts such as imagery for students to understand. Therefore, if students are unable to effectively interpret the depth perception cues, then this would mean that students would have a challenge in comprehending the visuals images used in the curriculum. An example of a depth perception cue is depicted in Figure 2.3.

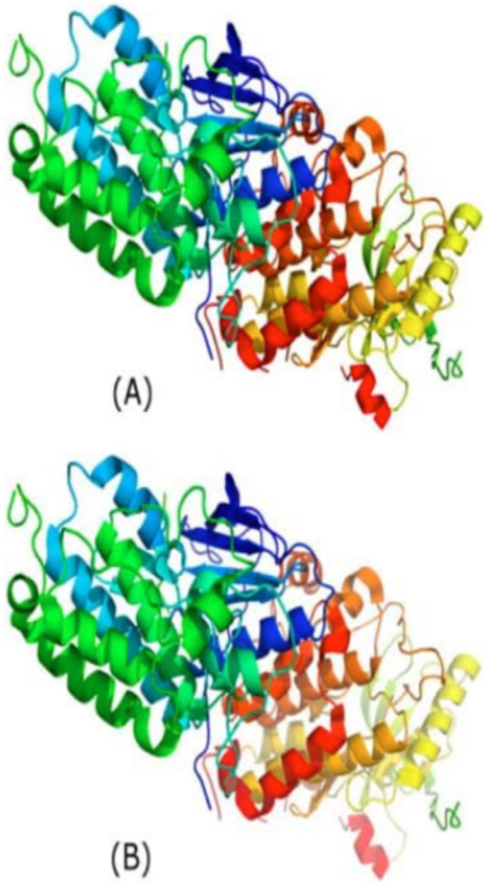


Figure 2.3: Depicts how PyMol overlays fog as the depth cue on the EGF receptor (a) is without depth perception cueing, (b) is with depth perception cueing. This fog helps to assist in emphasizing what is in the foreground and what is in the background of the image (Kaushik & Rath, 2019).

Cognitive psychology can be useful in science education, especially in assisting science educators to better understand how students represent knowledge in their minds. According to Sternberg and Sternberg (2009), knowledge can be stored in our minds as pictures, words or even abstract propositions. Sternberg and Sternberg (2009) further states that some ideas are better or more easily represented as pictures, while others are just best represented as words. An example would be the process of DNA replication. Students tend to find it a bit easier to explain DNA replication using pictures than words. Figure 2.4 denotes the process of DNA replication which is fully illustrated using images. On the contrary, students still find it simpler to explain the abstract concept of time using words rather than pictures.

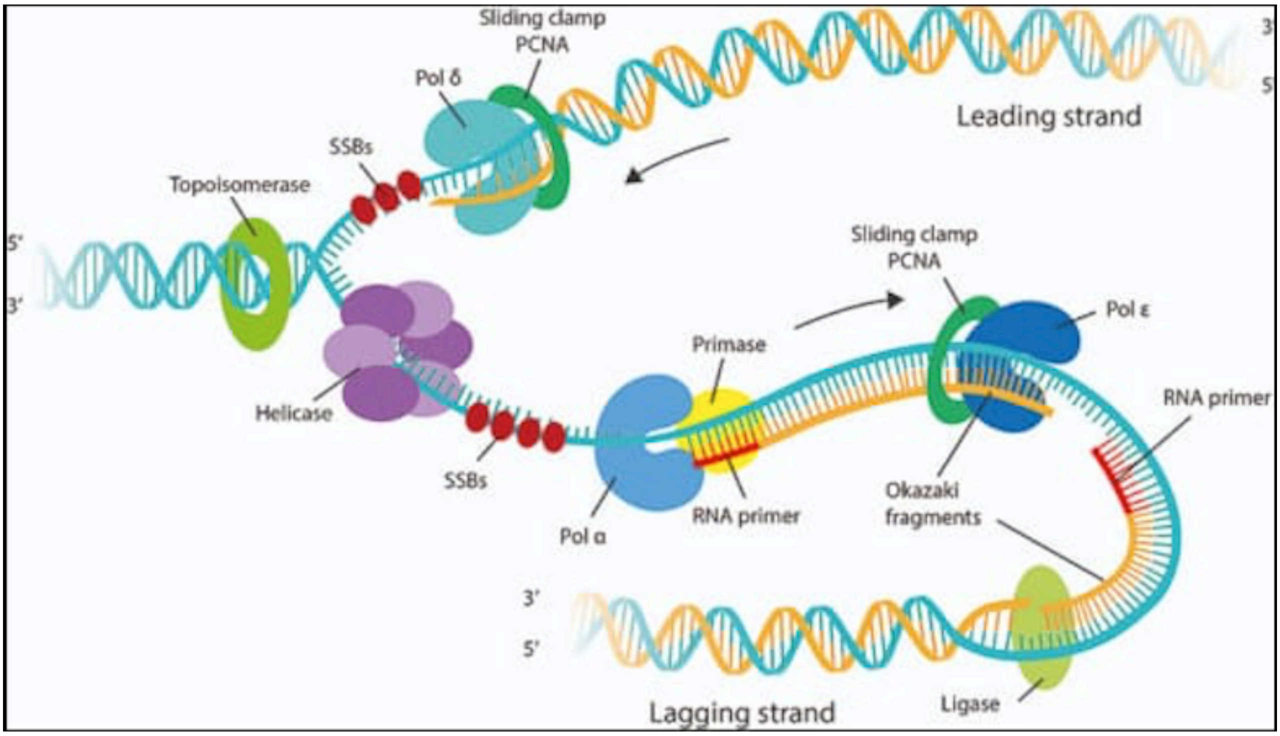


Figure 2.4 Illustration of the process of DNA Replication. Retrieved from https://www.mechanobio.info/genome-regulation/how-is-dna-replicated/

2.5 Role of language in science education

2.5.1 Relationship between language and perception

According to Landau, Aziz-Zadeh and Ivry (2010), "perception and language provides two primary means to access conceptual knowledge" (p.15254). The idea that languages guides our cognition was proposed by Whorf (1956), who postulated that an individual's cognition is sharpened by his or her language. This proposition depicts that perception of an object is done through their language. In fact, it is believed that the greater the language acquisition one has, the greater the chances of perception. This is why language and perception are regarded the two components of the central system (Vulchanova et al, 2019).

2.5.2 Relationship between language and reasoning

Does language influence how we think? Do we speak because we think, or we do think because we have language? Studies show that we use language to construct our internal thoughts (Stok, 2019). In fact, according to the same researcher, thinking involves cognitive thoughts that require the use of language, and that is why humans are set apart from animals. This emphasizes the importance of language in reasoning. In actual fact, without language we are unable to reason. Following the above argument, the current researcher deems that in the context of a diverse language classroom, there would be a variation in the level of VL skills among the students, simply because of the different languages spoken in the classroom.

Papafragou (2017) is in support of that above argument. As a matter of fact, the researcher deems that language has the potential to influence cognitive process. Furthermore, language is deemed to be important in the visual processing of objects with regards to space, size, shape and color of the object (Boroditsky, 2009). One can say, for a person to be able to discriminate between the colors of an object, there needs to be a vocabulary available to distinguish between the different colors, more so, the description will be dependent on the availability of the vocabulary in the language that one speaks.

2.5.3 Effect of mother tongue language in science education

While there are many factors involved in delivering science education, language remains the key component of communication and understanding of science. Noormohamadi (2008), deems that mother tongue language plays a central part in education, more especially an integral part of intellectual ability. Developing countries like South Africa are characterized by societal multilinguistic, yet they continue to allow a single foreign language to dominate the education sector. English has been widely accepted as the language to use to access high quality of education. However, proficiency of the language can affect comprehension of content (Park, 2016). Hence the success of students whose mother tongue language is not English is compromised in subjects like mathematics and science (Moschkovich, 2002).

2.6 Cognitive skills central to VL

According to Alonso (2018), VL is regarded as a set of cognitive skills which allow for visual communication and can (and should) be explicitly taught to the students to become visually literate (Williams, 2000). Dahmann (2016) states that cognitive skills are either fluid intelligence or crystalized intelligence. Fluid intelligence refers to the inborn skills or abilities such as reasoning capability, level of comprehension or the capability to process information. Crystalized intelligence expresses learned knowledge, skills or abilities. These include the skill or ability to learn to read, write or count. Crystalized intelligence also refers to the facts or theories that an individual has acquired overtime. Studies show that crystalized intelligence forms an important part of cognitive skills and is influenced by education, and thus can be acquired overtime. However, Messaris (2012) deems that VL cannot be acquired through education alone, but rather through personal experience and "socialisation". In light of the above discourse, Schönborn and Anderson (2010) proposed eight cognitive skills that they view to be central in visualisation and thus regard them as VL skills (Table 2.1).

Table 2.1 Biochemistry VL skills.

Decode the symbolic language composing a representation.
Evaluate the power, limitations and quality of a representation.
Interpret and use a representation to solve a problem.
Spatially manipulate a representation to interpret and explain a concept.
Construct a representation to explain a concept or solve a problem.
Translate horizontally across multiple representations of a concept.
Translate vertically between representations that depict various levels of organization and complexity.
Visualize orders of magnitude, relative size and scale.

With regards to the above-mentioned skills, one would ask which of these VL skills (Table 2.1) are important in science education? Linenberger and Holme (2015) developed a "needs assessment survey" which was aimed at determining the type of representation biochemistry educators would deem as valuable in an online biochemistry exam? The researchers believe that educators are the ones at the forefront of developing students' VL and therefore would know which VL skills (Table 2.1) are essential to develop in science, particularly in biochemistry. Collected data was based on the current development and assessment of VL skills in biochemistry courses. Based on VL skills (Table 2.1), the educators where asked to rank the top three VL skills that they perceived to be important to develop in biochemistry students.

By combining all ranked, the results suggested that only two skills were considered by the majority of the educators to be developed during the course of biochemistry i.e. 1) “constructing a representation to explain a concept or solve a problem” and 2) “interpreting and using a representation to solve a problem”. The two VL skills that attracted less attention from the biochemistry educators were: 1) “understanding and moving between multiple representations of the same system at the same level of organization” and 2) “visualising orders of magnitude, relative size and scale”. Thus, in biochemistry, students are not required to be estimating the magnitude, relative size or scale of objects which would be essential in physical science. However, for “understanding and moving between multiple representations of the same system at the same level of organization” not to be developed during the course of biochemistry is quite alarming. As discussed already, the characterisation of ERs reduces the cognitive load, by allowing students to only handle ERs of the same levels of abstraction individually. This simplifies the visualisation process of ERs. Therefore, the current researcher deems that the above mentioned VL skill is important in biochemistry, and should actually be one of the basic skills that students acquire at 1st year level.

In addition to the above-mentioned study, Mnguni et al. (2016) identified 24 cognitive skills that they deem as visualizations skills (Table 2.1). Linenberger and Holeme (2015) supports this study. Both studies show that what educators perceive to be important VL skills among biochemistry students are skills that students have not yet acquired. As stated before, experts tend to have greater knowledge on the subject matter than students and are thus more visually literate than students (Lowe, 2003). This is why educators tend to assume that students are visually literate, as they should have automatically acquired VSs during their many years of science education. Mnguni et al. (2016) affirms this argument with the notion that the VSs (Table 2.1) are crucial for biochemistry education and should be explicitly taught during the course of biochemistry.

Table 2.2. List of VSs required for VL (Mnguni et al., 2016).

Visualisation stage	Visualisation skills	Visualisation skills definition	Visualisation skill code
Internalisation	Arrange; order; organise; classify	To put into a specific order or relation through a methodical or systematic arrangement, or to arrange in a coherent form or pattern based on specific features	T02
	Depth perception; recognition of depth cues	To perceive spatial relationships and distances between objects, in multi-dimensions	T06
	Find; locate	To come upon or discover by searching or making an effort; to discover or ascertain through observation; to determine or specify the position or limits of by searching, examining.	T09
	Focus	To concentrate attention energy on something	T10
	Ground perception	To detect or perceive the part of a scene (or picture) that lies behind objects in the foreground	T11
	Perceive luminance; identify colours	To detect or perceive a visual attribute of things that result from the light they emit or transmit or reflect	T18
	Perceive motion	To recognise, discern, envision, or understand change of position in space and assign meaning to	T19
	Perceive speed	To recognise, discern, envision, or understand a rate of movement and meaning thereof	T20
	Perceive texture	To recognise, discern, envision, or understand the characteristic visual and tactile quality of the surface and meaning of such	T21
Conceptualisation	Analyse; interpret; assess; evaluate; examine; investigate	To break down into components or essential features by making sense of or assigning a meaning to, or give explanation and to examine or assess carefully; observe or inquire into in detail, by examining systematically; to observe carefully or critically.	T01
	Compare; relate	To examine and note the similarities or differences; bring into or link in logical or natural association, and establish or demonstrate a connection between	T03
	Critique	To critically examine and judge something	T05
	Imagine	To form a mental image of something that is not present or that is not given	T13
	Describe; discuss; explain	To make plain or comprehensible by adding details; to justify or offer reasons for or a cause, and give a description of, by conveying an idea or impression in speech or writing; characterise	T07
	Discriminate	To recognise or perceive the difference	T08
	Judge	To determine or declare after consideration or deliberation; to form an opinion or evaluation	T15
	Manipulate; mental rotation; recognise orientation; recognition; identify; identify shapes	To move, arrange, operate, or control cognitively in a skilful manner for examination purposes, and then to perceive multiple items with different orientation and/or shape to be the same if orientation and/or shape is rearranged	T16
	Recall; retrieve	To remember by retrieving information from memory	T23
Externalisation	Complete	To make whole, with all necessary or normal elements or parts	T04
	Illustrate; sketch	To clarify, as by use of examples or comparisons and to use drawings to describe roughly or briefly or give the main points or summary of	T12
	Infer; predict	To conclude by reasoning; in logic or reason or establish by deduction or state, tell about, or make known in advance, on the basis of special knowledge	T14
	Outline	To give the main features or various aspects of; summarise	T17
	Propose; develop; formulate; devise; construct; create; produce; invent	To cause to exist in a new or different form through artistic or imaginative effort	T22
	Use	To put into service or apply for a purpose	T24

According to Makarova, Makarova and Varaksa (2017), visualisation is associated with cognitive functions such as memory, perception, reflection and thinking. Thinking is considered as the process of generating mental imagery from external information. Adey and Shayer (1994) considers the process whereby one thinks about their thinking during learning to be the highest order of thinking known as metacognition. Metacognition actively involves controlling some of the cognitive processes such as planning the approach that one would use in a given learning task, monitoring comprehension, and evaluating one's progress during the process of complete a task (Livingston, 2003).

One of the most important points of visualisation is to have students learn how to think visually (Ozkan, Arikan, & Ozkan 2018). The process of transforming information and generating ERs is regarded as visual thinking. Visual thinking plays an important role in developing cognitive function to solve problems and think critically (Sholihah, Nusantara, Sa'Dijah & Susanto, 2019). The ability to visually think enables students to transition to higher levels of cognitive activity, therefore ensuring that students master the content. These types of students are said to have metavisualisation skills. Developing VSs in science education is considered to be of high importance. According to Makarova et al. (2017), VSs are not the type of skills that can be acquired automatically or can easily be transferred from an educator to a student during the inculcating of the prescribed content knowledge (Lowe, 2000). In line with and Schönborn & Anderson (2008), the current researcher reckons that metavisualisations are highly important skills to possess as a science student. In fact, the researcher believes that there is a great need for the education system to consider explicitly teaching VSs as part of the science curriculum. In actual fact, there is more of a need to train educators to facilitate the development of VSs in students.

2.7 Nature of VL based on the cognitive process of visualisation

With regards to the nature of VSs and VL in science education, there remains a gap in literature especially with regards to the cognitive process of visualisation (Mnguni, 2007). In light of the above disclosure, Mnguni (2014) explored two educational theoretical aspects associated with visualisation i.e. construction of knowledge using visual modes and theoretical cognitive process of visualisation to try and answer the following question: "how can VL be understood on the bases of the theoretical cognitive processes of visualisation in order to inform the understanding, teaching and studying of VL in science education?" (p.1).

2.7.1 Construction of knowledge using ERs

According to Mayer (2002), learning with the use of ERs is a cognitive process. Based on this theory, during the process of learning with ERs, the external images enter the cognitive structures through the eye to produce mental schema. Navaneedhan and Kamalanabhan (2017) regard cognitive structures as the basic mental patterns that people use to process and understand information. Rendering to this theory, students develop their own understanding of the content during their learning process by actively participating in the task or activities at hand, rather than all the information being "spoon feed" to them (Thompson, 1995; Mnguni, 2014). This is the same foundation upon which the educational theory of constructivism is based (Mnguni, 2014).

Constructivism is formulated on the notion that students "construct their own knowledge from experience, which is unique for each individual" (Singh & Yaduvashi, 2015, p. 1). According to Singh and Yaduvashi, (2015) "constructivism represents a paradigm shift from behaviourism to cognitive theory" (p. 1). A behaviourist believes that the success of students' during their learning process depends on the following focus areas i.e. student's intelligence, the domain of the objectives set for the lesson, the levels of the presented knowledge and reinforcing what has already been taught. In contrast to behaviourism, constructivists believe that the way students interact with their environment determines the success of their learning (Singh & Yaduvashi, 2015).

Constructivism theory is established on the following assumptions: 1) students physically construct their own knowledge when they are actively involved in the learning activities; 2) knowledge is symbolically constructed by students who can make their own external representation of the information that is presented; 3) knowledge is socially constructed when students are able to convey to others whatever new information they have acquired; 4) Knowledge is theoretically constructed when students are able to explain abstract phenomena in their own words (Singh & Yaduvashi, 2015).

According to Singh and Yaduvashi (2015), to ensure a better learning experience for students, Robert Karplus proposed a model that is better known as the as the 5Es. This model employs the 5Es, which describe the five phases of learning.

Engage phase deals with students retrieving prior knowledge which is used to connect with the information that is being presented. The activities in the lesson are set to motivate the students to use their thinking skills in order to make a connection on how prior knowledge links to what is taught currently. This phase requires the students to be mentally engaged during the learning process. *Explore* on the other hand, depicts the teacher setting up the classroom in way that will ensure that students engage in activities that are tangible and which symbolises a real-life experience which they can then reflect on as they continue to build on concepts, processes and skills. *Explain* phase is where students are able to better understand what was previously taught and explored. Here the teacher would set up activities that will require students to explain to their peers what they have learned, to try to make better sense of the concepts, processes and skills. By asking students to explain their understanding to their peers helps the students to refine their own understanding. *Elaborate* involves the teacher giving the students the opportunity to apply their knowledge to day to day life situations. Here the students are able to expand on their conceptual knowledge. *Evaluate* phase encourages students to reflect on what they have learned. This allows the students to assess their own understanding of concepts and process by evaluating their own progress. This stage also enables the teacher to assess students understanding of concepts, process and development of skills.

Constructivism in the modern classroom means moving away from the conventional way of teaching where the focus was more on the teacher rather than the student. Lessons become more student centred than teacher centred. In this framework, students are aware of their environment while constructing their own knowledge and creating their own mental images to make meaning of the content. Skills such as problem-solving skill, critical and reflective thinking are also enhanced during the lessons as students' progress through the 5Es. Cognitive skills are also essential skills to develop, more especially when having to analyse and interpret ERs that are mostly used in the science curriculum.

By linking the constructivism theory along with Mayer's (2003) cognitive theory of multimedia learning, the relationship between the two theories lies as the backbone of the current study. Merging the two theories will assist us as educators to better understand how students process

ERs. Additionally, this will also assist us to better understand how we can assist the students in developing visual conceptual knowledge.

Mnguni (2014) deems that when learning with ERs, the process of visualisation consists of three stages i.e. understanding of visual information, processing of the visual information in the brain and externalising the information as visual models. In line with the above-mentioned relationship between the two theories, Mnguni (2014) formulated the definition of visualisation which the researcher regards as "the ability to select and effectively use cognitive skills for perceiving, processing and producing ERs" (p. 2).

A constructivist classroom is grounded on the teacher's role changing from being a "transmitter of knowledge to a facilitator of knowledge" (Singh & Yaduvashi, 2015, p. 2), while the role of the student changes from being "a knowledge gainer to a knowledge constructor" (Singh & Yaduvashi, 2015, p. 2). However, similar to Mayer (2003) with the cognitive theory of multimedia learning, the teacher still plays an important role in assisting students to develop mental images of what they are learning. This can be done "by illustrating the content with graphical representation, visualisation of diagrams as well as through symbolic and abstract thinking" (Navaneedhan & Kamalanabhan, 2017, p. 90), which is the essence of VL.

With the teacher facilitating knowledge in this manner, students are able to construct mental images of the ERs in their brains, within their working memory. According to Cockcroft (2015), working memory refers to the cognitive system that enables humans to mentally hold small amounts of information, while processing the information. Cognitive system denotes the brain system that enables us to understand, reason and learn. Just like the short-term memory, the working memory has limited capacity, meaning it can only retain small amounts of information at a time. In contrast to short-term memory, the working memory is able to process information, thus enabling one to achieve any task that requires manipulation of information, such as planning, reasoning and problem solving.

Once the image is imprinted within the working memory, the student will then be able to arrange the set of mental images into a coherent mental representation called a pictorial model. Thompson (1995) believes that students construct knowledge by selecting the information which seems easier for them to understand, will enable them to construct hypothesis and thus enable them to make decisions which are formed on existing knowledge, which in turn will be stored in the long-term memory as mental schema. The stored mental schema is easily accessible and will in turn be processed in the working memory when needed. In some instances, the mental schema can be retrieved as ERs, for example drawing a picture on paper. This is supported by Gilbert (2005) who states that the mental images formed using ERs are kept in the long-term memory and are easily reached, thus reducing the cognitive load.

2.7.2 The theoretical cognitive process of visualisation

According to Mnguni (2014), similar to the constructivism and cognitive theory of multimedia learning, the theoretical cognitive process of visualisation proposes that the process of learning actually involves the input of information from the external environment, which in turn goes to the cognitive structures where the information is processed, and then externalized. Therefore, in line with Mnguni (2014), one can say that the theoretical cognitive process of visualisation involves the internal and external domains interacting with one another to process VI and externalizing what is understood from the information.

Mnguni (2014) deems that the cognitive process of visualisation can be divided into three non-linear overlapping stages i.e. internalisation of visual models (IVM), conceptualisation of visual models (CVM) and externalisation of visual models (EVM) (Figure 2.5).

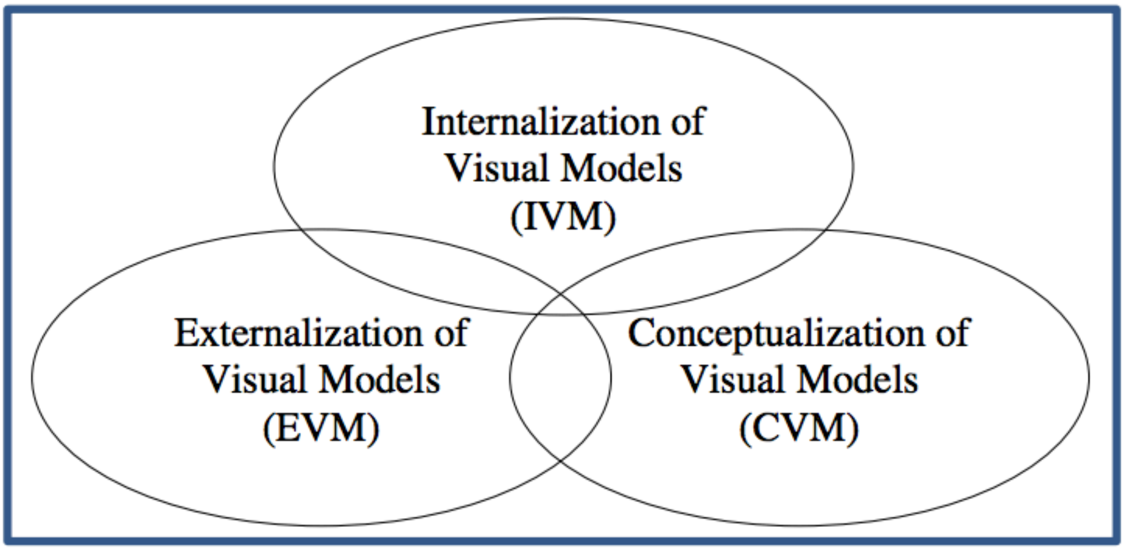


Figure 2.5 The overlapping stages of the cognitive process of visualisation (Mnguni, 2014).

In the above-mentioned model, the IVM refers to the "process whereby the sense organs such as the eyes work with the brains to absorb information from the world" (Mnguni, 2014, p. 3). The CMV is then the process whereby meaning is made from the gained formation and during which cognitive visual modes are constructed (Burton, 2004). EMV is the production of external visual models by expressing cognitive mental scheme (Mnguni, 2014).

Mnguni (2014) deems that the IVM model consists of three levels i.e. low-level, middle-level and high-level IVM. This level is believed to involve tasks that only require minimal cognitive effort such as "target detection, region tracking and counting" (Kawahara and Yokosawa, 2001, p. 2). Mnguni (2014) simplifies low-IVM by using an example whereby students were asked to differentiate between an animal cell and a plant cell that was based on a visual model. This example required the student to detect the presence or absence of organelles such as the presence of chloroplast and cell wall in a plant cell, and their absence in animal cell (Mnguni, 2014).

High-level IVM on the other hand involves the use of great amount of cognitive effort. According to Healey (2005), this level requires the use of prior knowledge to interpret ERs. Similar to the construction of knowledge using visual model theory, once the external visual information has entered the cognitive structures, the internalised information will then move into the working memory where the student will process the information and try to make meaning of it and therefore construct a mental schema.

Mnguni (2007) proposes that the IVM model is based on one learning skill which is the students' ability to comprehend or make meaning of scientific information on a given visual model. This proposition is drown on a study done by Mnguni (2014) where students were given ERs such as one shown in Figure 2.6, and were asked the significance of the grey area in the visual model. Some students found it challenging to associate the background information with the rest of the visual model. One student thought that the grey area of the visual model was the background to the main object which is the amino acid. It is clear that the student lacks prior knowledge that is associated with the ER that is depicted in Figure 2.6

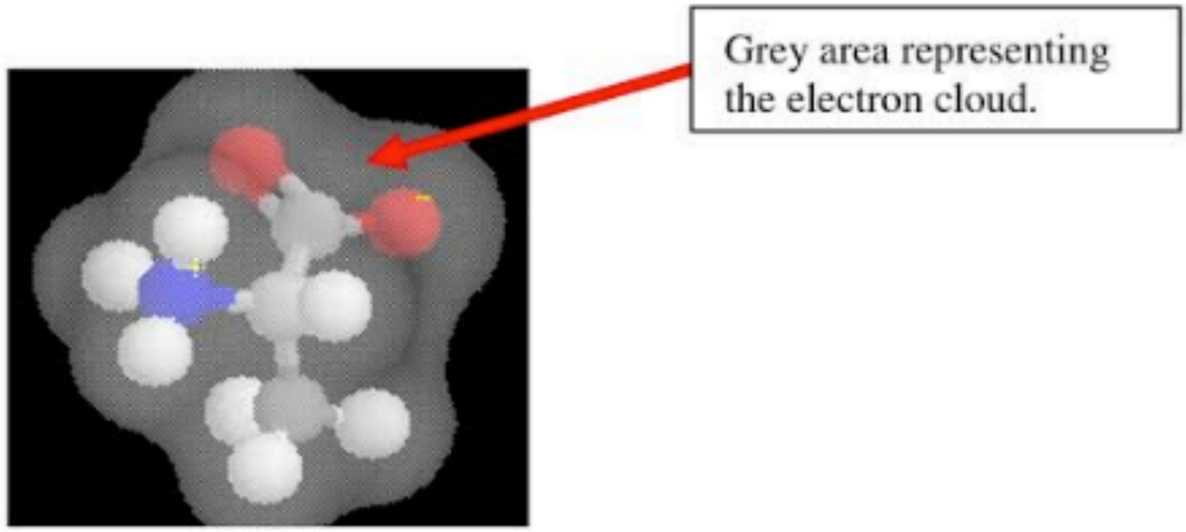


Figure 2.6 ER in which students perceived the electron cloud as a background (Mnguni, 2014).

According to Mnguni (2014), once the information has been internalized, CVM follows. CVM is also similar to IVM in that it also requires the use of prior knowledge to interpret visual models, thus overlapping with IVM. However, high-level IVM relies on working memory where information is processed and retained for a short period of time. CVM relies on short- and long-term memory for retaining internalized information. To understand how internalized information becomes conceptualized, DeSantis and Housen (2000) did a study whereby the researcher investigated how students process information, while viewing ERs "Housen model". The model is used to characterise people into different stages of cognitive processing during the process of visualization (DeSantis & Housen, 2000). The model is depicted in Table 2.3.

Table 2.3. The Housen model used to characterise people into different stages of cognitive processing based on their actions while viewing ERs of art work (DeSantis & Housen, 2000).

Stage	Action	Definition
1.	*Accountive*	Use senses, memories, emotions and personal associations, to make concrete observations about the work of art which gets woven into narrative.
2.	*Constructive*	Uses logical and accessible tools, such as own IVMs, knowledge, social values and morals. If the art work did not look the way it "supposed to" - craft skill, technique, hard work, utility and function were not evident – then the work of art would be considered weird and lacking value.
3.	*Classifying*	Analytical and critical skills come into service, identifies the art work as place, style, time and provenance. Decodes the art work using library of facts and figures that they are ready and eager to expand.
4.	*Interpretive*	Seek a personal encounter with the art work. Let's the meaning of the work slowly unfold; appreciate the subtleness of the lines, shapes and colours. Critical skills are put to service. Each encounter with the work presents a chance for new comparisons, insights and experiences
5.	*Re-creative*	Have established a long history of viewing and reflecting. A familiar painting would be like an old friend who is known intimately, yet full of surprises. Combines personal contemplation with views that broadly encompass universal concerns

The Housen model (Table 2.3) stipulates that the accountive stage is where students would conceptualize visual images based upon what is familiar to them as per long term memory (DeSantis & Housen, 2000). In the constructive stage, the students start to reason their IVM or prior knowledge and start making judgments about the ER (DeSantis & Housen, 2000). The visual image will only be understood by the students if it relates to any prior knowledge that the students may have. In the classifying stage, students would classify internalized information into different categories that is based on their memory (DeSantis & Housen, 2000). The interpretive stage allows for students to unfold the meaning of the visual image by itself, rather than the students imposing their own ideas of what they think the visual image means (Mnguni, 2014; DeSantis & Housen, 2000). Lastly, the re-creative stage allows for students to create new meaning of the visual image each time they view and reflect on it (DeSantis & Housen, 2000). DeSantis and Housen (2000) proposes that students can move from one stage of the model to another based on the new knowledge that they acquire.

Another theory that is used to explain how internalized information becomes conceptualized is the dual-coding theory. As mentioned already, according to this theory, the cognitive structure consists of two mental processing systems, which are the verbal and non-verbal systems (Clark and Paivo, 1991). The theory is derived from the notion that the brain constructs visual models in working memory from the connection of both verbal and ERs. Clark and Paivo, 1991 deems that the two mental processing systems work together to construct mental visual images which are memorized and stored in the long-term memory (Cockcroft, 2015).

However, since the working memory has a limited capacity for holding internalized information and making it readily accessible, the above-mentioned limitation is supported by the limited capacity theory. This theory suggests that if the two mental processing systems are overloaded with information, they will fail to connect. The working memory will not be able to access new information and construct mental images (Mayer & Anderson, 1992). Hence, Mnguni (2014) suggests that for effective CVM, the amount of information presented to each mental processing systems at a time is limited. Therefore, the use of visual imaging with minimal wording is necessary.

EVM is regarded as the last stage which is involved in the cognitive process of visualization. In this stage, the constructed mental images are believed to be externally expressed in the form of drawings or verbal description (Mnguni, 2014). In science education, the external expression of visual models can be classified into three levels. The first level is the macroscopic level where the students attempt to produce visual models of the phenomena as they are exposed to it, either by seeing, smelling, hearing, tasting or touching. The second level is the microscopic level where students attempt to produce visual images of the phenomena that they cannot see with their naked eye, and thus have no prior experience with it. Lastly, the symbolic level explains how students attempt to produce visual models of an abstract phenomenon such as a chemical equation depicting a chemical process such as the metabolism of glucose (Rundgren, Rundgren & Schönborn, 2010).

According to Mnguni (2014), the researcher deems that the students' ability to produce external, visual models is dependent on a number of factors such as bodily-kinesthetic, logic, or/and spatial/visual intelligence. To illustrate the importance of spatial/visual intelligence in science education, Mnguni (2007) conducted a study whereby the students' ability to produce external, visual models is based on their prior knowledge. The students were given an ER depicting part of biochemical process, namely protein synthesis, where a fragment of the process was purposefully removed, as shown in Figure 2.7.

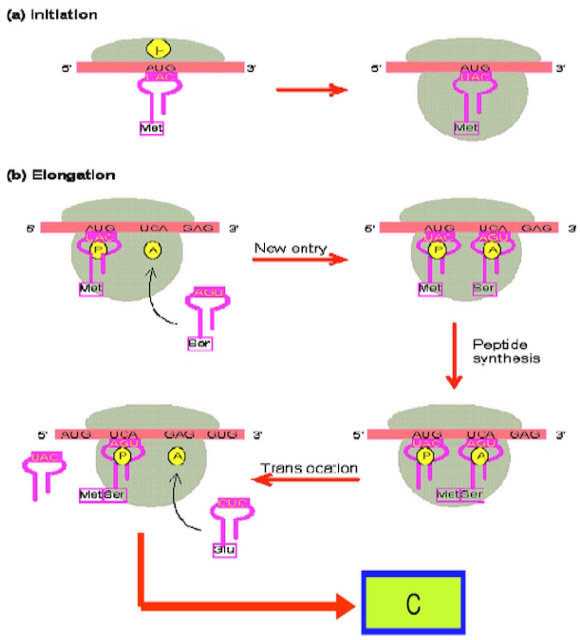


Figure 2.7 ER depicting biochemical process of protein synthesis with a portion of the process intentionally removed (Mnguni, 2007).

Students were required to draw an illustration predicting step(s) "C" in the given ER, assuming that the process had no stop codon. The study required students to be able to "IVM" and "CMV" to produce "EVM". Based on the results, about 58 % of the students were unable to use the information on the ER to produce "EVM".

However, even though some students were able to recognize the process and use the terminology correctly (indicating the presence of prior knowledge), some students failed to use the given steps “a” and “b” in the ER to produce “C”. This demonstrates the students’ inability to use their prior knowledge to produce external, visual models. On the contrary, it could be the case where the students incorrectly interpreted the ER associated with process, because it was just their first time being exposed to the phenomena.

West (1997) believes that students will attempt to produce external visual models which match their mental schema that they had previously formed. Consequently, if the information about the phenomena was initially incorrectly internalized and conceptualized due to lack of VSs, this would indicate the lack of spatial/visual intelligence, and thus the misconception of the phenomena would be created.

As seen in this literature review, VSs are essential skills to have for all students in science education, more so especially in molecular biology. More and more literature is recognising the importance of VL. However, with the proliferation of ERs used in students’ textbooks particularly molecular biology, some educators still undertake that notion that the development of VL skills is solely dependent on the students. They feel that the skills are acquired automatically during the imparting of content knowledge, which is not the case. (Mnguni et al., 2016).

As science educators, we need to expose our students to the varied levels of abstraction to ease the cognitive load of processing ERs. Based on the literature cited in the current literature review, students will benefit immensely from having their level of VL developed or improved. Educators can assist students by explicitly teaching them how to effectively interpret ERs to avoid misconceptions. Conversely, educators cannot do this unless they themselves understand how students perceive and process visual information to produce external visual models.

Furthermore, it has been reiterated how important language is in the perception of objects. Therefore, it is highly imperative that as educators, we understand this notion and consider the diverse backgrounds that our students are coming from, more especially with regards to the different languages we encounter in our classrooms.

2.8 Theoretical Framework

In line with Mnguni (2019), the theoretical framework informing the current study is based on the following theoretical perspectives:

The linguistic relativity theory states that language effects cognition and perception of a person (Masharov & Fisher, 2006). In order to get deeper into understanding the relationship between mother tongue language and VSs which are required by students in molecular biology, it is vital to realize as educators that once a student steps into the classroom, they bring with them all their personality features including their beliefs and attitudes into the learning environment (Hosseini & Pourmandia, 2013). Student's attitude towards the importance of VL will also determine their success in enhancing their VL skills. Defining "attitudes" can be quite tricky, especially when connected to the language relativity hypothesis. However, for the purpose of the current study, attitudes towards learning molecular biology in one's own mother tongue can be defined as beliefs, feelings, stereotypes, and judgements that a learner may have (Latchanna & Dagnew, 2009). In light of the above discourse, the current researcher decided to use the linguistic relativity hypothesis to investigate the relationship between mother tongue language and visual cognitive skills when interpreting ERs in molecular biology.

Cognitive skills that contribute to VL (Mnguni et al., 2016). The current researcher supports the argument made by Mnguni et al. (2016) that "students lack the cognitive skills required for optimal VL skills which are needed for processing and constructing meaning from ERs". In order to understand which of these cognitive skills are required by students, we need to understand how visual information is perceived and processed to result in the production of visual models, which is the essence of VL. However, due to the lack of a universal theory of VL as stated by Mnguni (2019), developing and assessing VSs can be quit challenging. Nonetheless, Mnguni et al., (2016) identified 24 VSs (Table 2.2) using the taxonomy of teaching, learning and assessing known as Blooms taxonomy (Anderson et al., 2001). The taxonomy was revised to identify cognitive skills that are required in each step of the theoretical cognitive process of visualisation (as discussed in section 2.7.2) (Mnguni et al., 2016). The theoretical framework of the current study is based on this theoretical perspective. Table 2.2 is used to develop the instrument to analyse the VSs which are required by 1st year molecular biology students to effectively interpret the ERs used to explain mRNA translation.

Instructional representations can be characterised according to the levels of an abstraction (Offerdahl, Arneson & Byrne, 2017). The researcher drew the theoretical framework for the current study from a validated model developed by Schönborn and Anderson (2010) which identified factors that are involved in successfully interpreting ERs. The factors include:

a) An individual's content knowledge

b) An individual's ability to reason

c) The visual characteristics of the ERs

The current researcher supports the argument made by Schönborn and Anderson (2009) that in order to develop students' VL skills, undergraduate biology students should be specifically taught the skills and be given ample opportunities to interact with the specific ERs. As already discussed (Section 2.2), the researcher developed a taxonomy which is used to characterise levels of abstraction in instructional representations (Figure 2.2). The taxonomy (Figure 2.2) serves as a checklist for the current study to develop an instrument for data collection and data analysis in order to identify the nature of VSs which are required by 1st year molecular biology students when learning about mRNA translation.

On the basis of these fundamental theoretical perspectives, the current researcher deems that in order to understand factors that affect VL such as language, varied levels of ERs and type of VSs required to effectively interpret ERs, it is important that we understand the significance of the theoretical, cognitive process of visualisation which is the essence of VL.

The theoretical cognitive process of visualisation is used as the "glue" in the current study's theoretical framework to bring all the theoretical perspectives together in order to develop a solid framework that informs the development of the instruments to be used for data collection and data analysis. In relation to the current study, Mnguni (2014) also stipulates that when assessing VSs, they can only to be identified in the context of the subject which in this case is molecular biology.

The crux of the theoretical framework (Figure 2.8) of study is based on the importance of assessing the different VSs required by students to effectively interpret ERs, by characterising the different ERs. This can assist students to lighten the cognitive load. However, language also affects the perceptions of ERs. Thus, when implementing strategies to improve students visualisation, the type of language that is used in the science curriculum should also be accounted for.

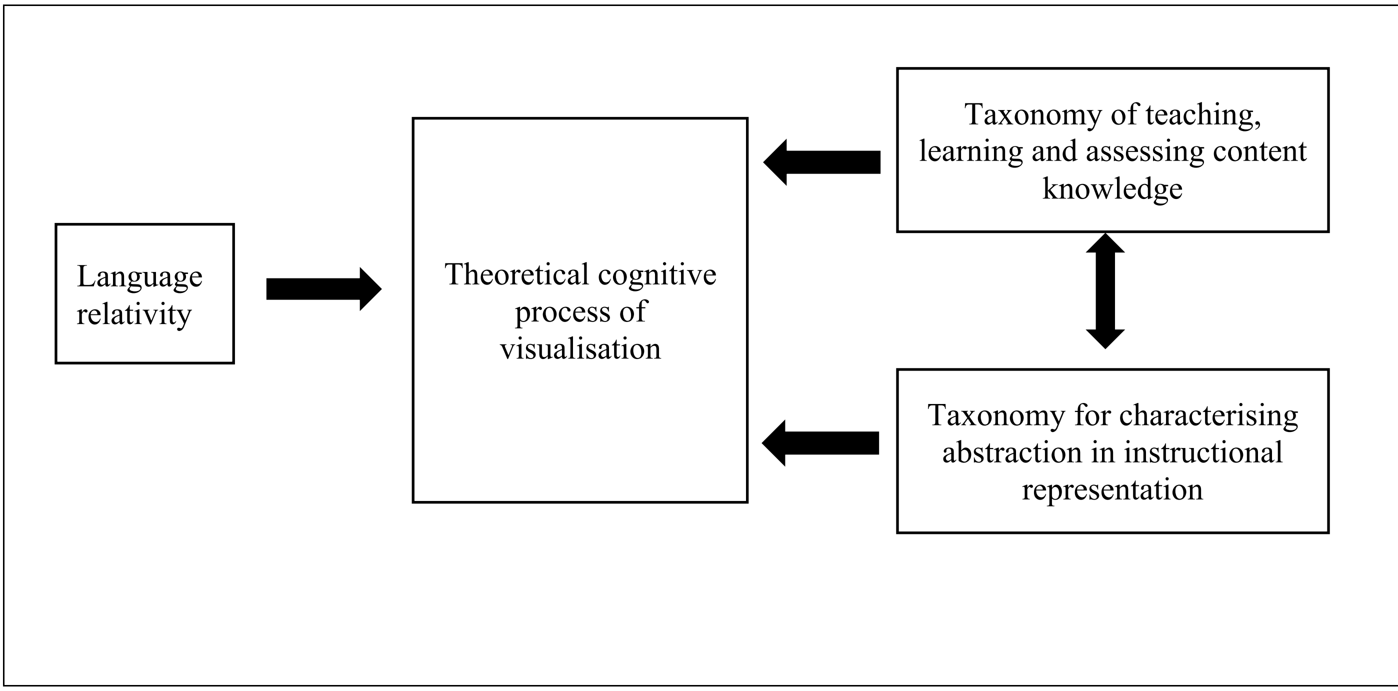


Figure 2.8 Theoretical framework used to inform the current study

The above-mentioned theoretical framework (Figure 2.8) will be used in guiding the researchers' choice of methods for data collection and analysis. In order to investigate the nature of VSs that are required by 1st year molecular biology students to effectively interpret ERs, the taxonomy of teaching, learning and assessing content knowledge will be used to identify the type of VSs. The identified VSs (Mnguni et al., 2016) will be used to identify which of the VSs are required to process ERs that are used to explain mRNA translation at each stage of the cognitive process of visualisation (i.e. IVM, CVM, and EVM).

In line with the above, in order to identify the external nature of the ERs which are used when learning about mRNA translation during 1st year university molecular biology course, the taxonomy for characterising abstractions in instructional representation will be used to classify the ERs either as symbolic, schematic, graphic or as cartoons or realistic images (Offerdahl et al., 2017). According to Mnguni (2019), students require specific VSs in order to be able to learn through the different levels of abstraction and effectively internalise, conceptualise and externalise the ERs.

Lastly, by using the language relativity theory, the researcher will be able to explore the extent to which learning in their mother tongue affects how students interpret ERs that are used in explaining mRNA translation. This will be done by investigating students' attitudes towards mother tongue education and to investigate if they believe that it affects their interpretation of ERs in the explanation of mRNA translation.

2.9 Conclusion

To summarise, it is clearly evident that molecular biology students have a challenge with constructing meaning from ERs used in the curriculum. The challenge lies with their ability to interpret and evaluate the ERs correctly. As indicated by Offerdahl et al. (2017), assessments are a way that lecturers communicate what is expected of students in terms of the nature of knowledge that students are required to possess. However, it is also important that the lecturers clearly communicate the nature of the VSs which are required in the discipline.

Literature indicates that language plays an important role in communicating and understanding science. The current researcher argues that the mother tongue (first language education) plays an integral role in science education, particularly in molecular biology education. Therefore, the researcher proposed that students should be taught in the language of their mother tongue. This is because students who are taught molecular biology in the second language such as English tend to have a low-level proficiency in that language, which could compromise the comprehension of the subject matter.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Introduction

The current chapter describes the action plan undertaken by the researcher to investigate the research problem of the study. Here the researcher discusses the rationale of how the specific procedures or techniques will be applied in identifying, selecting, processing and analysing information in order to understand the research problem (Bryman, 2008). With regards to the current study, the nature of the study, specific approaches, designs, methods and procedures were used in collecting and analysing data during different times of the study.

The methodology section also addresses an important component of research which is the reproducibility of the study. Here the researcher reflects on the validity and reliability of the research.

3.2 Research paradigm

Understanding and setting the research paradigm is one of the most crucial steps in conducting research (Kivunja & Kuyini, 2017). Rehman and Alharthi (2016) suggest that "as researchers we need to be able to understand and clearly articulate our beliefs about the nature of reality, what can be known about it and how we can go about attaining this knowledge" (p.51). In essence, paradigms are our way of understanding the world we live in (Rehman & Alharthi, 2016).

Research paradigms are based on making assumptions about ontology, epistemology, and methodology (Kivunja & Kuyini, 2017). Each of these is discussed below in relation to the current research study. *Ontology* refers to the nature of our beliefs about reality (Richards, 2003). This component of the research paradigm is based on the assumptions about reality, how it exists and what can be known about it (Rehman & Alharthi, 2016). Ontology underlines your belief system as a researcher about the nature of reality. According to Kivunja and Kuyini (2017), philosophical assumptions about the nature of reality are very important in understanding or making meaning of the data that a researcher gathers in their study. Additionally, the philosophical assumptions or concepts help to direct the researcher's thinking about the research problem in their study, its significance and the approach that the researcher can take in order to get a "solution" to the problem.

Epistemology refers to “the branch of philosophy that studies the nature of knowledge and the process by which knowledge is acquired and validated”(Gall, Gall, & Borg, 2003, p.1). According to Cohen, Manion and Morrison (2007), epistemology is concerned with the nature and forms of knowledge, such as how knowledge is formed, how it can be acquired and how it can be communicated to other people. It focuses on the nature of knowledge that a researcher can acquire in order to broaden and deepen their understanding about the research problem. Therefore, in order to understand the epistemology of a research, the researcher needs to ask a very important question i.e. how do we know what we know? This question lies at the basis of investigating the truth about a phenomenon (Kivunja & Kuyini, 2017).

Methodology is a broad term that refers to the research design, methods, approaches and procedures that are used in a study (Rehman & Alharthi, 2016, p. 52). This includes data collection process, the participants involved in the study, the instruments used to collect the data, and the chosen data analysis methods. In summary, the methodology guides the researcher in deciding what type of data is required for the study and which data collection and data analysis tools will be most appropriate for the study (Ellis, 2013).

Lastly*, methods* refer to “specific means of collecting data and analysing data” (Rehman & Alharthi, 2016, p. 52). These are specific procedures that the researcher will follow order to gather and analyse data for their study. The data collection and analysis methods to be chosen for a study will depend on the type of data that is required by the researcher (Kivunja & Kuyini, 2017). For example, the researcher has a choice between quantitative and qualitative data collecting and analysis methods (which will be discussed further in 3.3). For a research study that questions ideas or experiences or studies a phenomenon that cannot quantified, the researcher will collect data qualitatively. When studies require a more systematic understanding of a topic or where research involves the testing of a hypothesis, then the researcher would collect data quantitatively.

Constructivism, positivism and realism are some of the most widely adopted research paradigms in educational research and all these paradigms assume specific ontological, epistemological, methodological and methods in a research study (Kivunja & Kuyini, 2017).
Constructivism paradigm is described as an “approach that asserts that people construct their own understanding and knowledge of the world through experiencing things and reflecting upon those things” (Adom, Yeboah & Ankra, 2016, p. 2). As stated in Chapter 2,

constructivism is based on the notion that student interaction with their environment determines the success of their learning (Singh & Yaduvashi, 2015). In the modern classroom, a constructivist classroom would focus more on the students, and the teacher would assume the role as facilitator. Lessons are more student centred and students are actively aware of their environment, while constructing their own knowledge. In research, this paradigm is mostly used in scientific or observation studies where the researcher is mostly passionate about how people learn. Data can be collected through in-depth interviews and participant observation (Sobh & Perry, 2005).

According to Crotty (1988), *positivism paradigm* is described as the philosophical approach that is based on the notion that researchers can only understand human behaviour through observation and reason (Kivunja & Kuyini, 2017). This paradigm adheres to the notion that only facts that are obtained through observation are considered to be valid and trustworthy. Positivism paradigm is deeply rooted in the idea that whatever exists can be verified through experiments or statistics. This is why this paradigm is widely used in science and mathematics research studies (Sobh & Perry, 2005) and thus must be measured and supported by evidence. According to Taylor and Medina (2013), this scientific research paradigm "strives to investigate, confirm and predict law like patterns of behaviour, and is commonly used in research to test theories or hypotheses" (p. 2).

Lastly, *realism paradigm* refers to a philosophical approach that relies on the idea of independence of reality from human mind (Dudovskiy, 2016). According to Sobh and Perry (2005), the philosophical position of this paradigm is that reality exists independently of the researcher's mind. Meaning that there is an external reality (Bhaskar, 1978), which exists independently from the researcher's perception. Realism can be divided into two groups i.e. direct and critical. Direct realism regards the 'observable world' as the 'real world,' meaning that what you see is what you get. Critical realism distinguishes between the 'observable' world and the 'real' world. This means that even though humans observe the world a certain way, human perception does not necessarily reflect the real world as the real world exists independent from human perception.

In an attempt to answer the two-research questions, the current researcher adopted the positivism paradigm. In order to support the paradigm, the theoretical framework (section 2.8) was used to develop strategies, instruments for data collection and analysis, along with methods to be used for data interpretation for the current study.

According to Kivunja and Kuyini (2017), the positivism paradigm is preferred as the worldview for research. Often positivists believe that it is important for a researcher to detach themselves from the research process, by minimising their interaction with the participants in order to remain objective. In a positivism study, the researcher's role is limited to data collection and interpretation in an objective manner. The research tends to produce quantifiable data which is often analysed statistically. In addition, the data is usually collected in value-free manner which is economical for both the researcher and the participants.

The positivism paradigm also carries the belief that valid knowledge or evidence can only be obtained through observation by using senses such sight, smell, touch, taste and hearing. In this regard, data can be collected either directly by observation or indirectly with the use of a value-free instrument. However, according to Bryman (2007), "things that cannot be seen (observed), for instance people's thoughts and attitudes cannot be accepted as valid evidence and knowledge" (p. 15). Nonetheless, Buchana (1998) argues that "at the core of the positivism paradigm is the principle of verification. According to the verification principle, one can distinguish valid knowledge from even personal opinion" (p. 441). This can include peoples' attitudes or perception, as long as there is means to confirm or verify the given statements used in the instrument with methods of validity and reliability.

In conclusion, the positivism paradigm is driven by two important principles which is to isolate, analyse and understand human behaviour. The second important principle of positivism is the objectivity. According to Gratton and Jones (2004), the level of objectivity with regards to the positivism paradigm "allows to facilitate replication of the methods used in the research study and also allows for quantifiable observations for statistical analysis" (p. 215). In view of this, the current researcher chooses this paradigm to be suitable for the study as the generated data will be independent of the researcher's bias.

3.3 Research approach

Having adopted the positivism paradigm for the current research study, the researcher went on to adopt a specific research approach through which the research questions will be answered. A research approach is a plan of action undertaken by the researcher to give direction to conducted research both thoroughly and efficiently (Mohajan, 2019). There are three main types of approaches used to collect data, i.e. qualitative, quantitative and mixed-methods approach (Creswell, 2009).

3.3.1 Quantitative research approach

According to Mohajan (2017), researchers typically select this approach to respond to research questions that require numerical data. Furthermore, the quantitative approach supports the positivist paradigm, due to the reason that human behaviour can only be understood through observation and reason. Quantitative approaches are known to be well structured and any divergence will have to be supported by substantial arguments (Mnguni, 2007). This makes the approach replicable since the research approach solely relies on hypothesis and testing. The researcher does not need to depend on guesswork, but follows clear guidelines and objectives to conduct the study (Lichtman, 2013). Another advantage of using the quantitative research approach is to allow the researcher to study larger sample sizes for any hypothesis to be proven or disproven which makes it easier to reach accurate, generalised conclusions (Sharpe, 2008). As already indicated, the quantitative approach eliminates researcher bias as the researcher is not directly involved with the participants, more especially when data is collected by methods such as surveys or questionnaires (Daniel, 2016). Therefore, quantitative methods includes the use of statistical tools to collect and analyse data which saves on time and resources (Daniel, 2016).

Even though the quantitative approach possesses a number of advantages, it also has its own weaknesses. While this approach works perfectly well in controlled conditions such as in a laboratory, measuring phenomena like human behaviour in natural settings can be a bit difficult, as survey instruments are known to are prone to errors, especially with flawed sampling techniques (Sharpe, 2008).

3.3.2 Qualitative research approach

Qualitative research approach uses a more realistic approach to study a phenomenon in a context specific setting (Maxwell, 2018). Unlike the quantitative approach, the qualitative approach includes the use of methods such as one-on-one interviews and field notes which are used to collect data from the participants in their natural settings (Daniel, 2016).

The qualitative approach is mostly preferred by researchers who wish to obtain abundant data about real life people and their natural settings (Teherani et al., 2015). In contrast to the quantitative approach, the qualitative research approach is known to be more dependent upon the researcher's personal beliefs with regards to the type of data collected and the method the researcher chooses to use to collect and analyse data. This poses a threat to the validity and reliability of the data (Mnguni, 2007), as the study would rely on the logic of the approach that the researcher decided to use to collect and analyse their data (Kurdziel & Libarkin, 2002).

3.3.3 Mixed methods approach

Mixed methods approach provides the researcher with a broader and more in-depth knowledge about the phenomenon being investigated. According to Johnson, Onweugbuzi and Turner (2017), a mixed methods approach attempts to study several ideas and opinions in order to develop a well-balanced research. Consequently, the approach provides complimentary information that would make up for the short coming of just using only one method, and thus serves to strengthen the research findings (Wisdom, 2013).

However, there is the need to resolve whether this approach is viable and more importantly credible (Scott, 2014). Scott (2014) provides an argument which has been suggested to support this approach. By integrating the qualitative and quantitative methods, this allows for the development of a mixed methods framework which is coherent and which provides a warranty through triangulation. Scott (2014) further adds that this argument accepts that both quantitative and qualitative approaches have different epistemic and ontological bases. Nevertheless, if both approaches are focused on the same research, they provide the study with a greater degree of validity and reliability. Therefore, the integration of qualitative and quantitative research approaches increases the reliability and validity of the study.

Following the positivism paradigm, the quantitative research approach was followed. According to Saunders, Lewis and Thornbill (2000), when a theoretical framework (section 2.8) and a hypothesis (section 1.2) has been developed and a research strategy has been designed in order to test the hypothesis, then the chosen research approach would be deductive. However, the research approach would be inductive if the theory was developed and if data was collected as a result of data analysis. Furthermore, unlike inductive reasoning, deductive reasoning is owing more to the positivism paradigm.

In line with Malhotra and Birks (2003), the current researcher finds the quantitative research approach to be more suitable for research studies that attempt to measure human attitudes or behaviour. In accordance to the positivism paradigm, the quantitative approach quantifies data by applying statistical analysis. Nevertheless, the current researcher acknowledges that there is an array of tools that are available for researchers to use to obtain data on student attitudes or behaviour such as qualitative analysis tools. These tools would involve doing interviews which would provide rich data on students' responses (Slater, Slater & Bailey, 2011). However, like any other research tool there are limitations which are associated with interviews. According to Hermanowicz (2002), while interviews seem to be the most "revealing and enjoyable method of collecting data, they are deceptively difficult" (p. 498). Unquestionably, large amounts of data are expected to be collected via interviews. Robson (2002) stipulates that, "interviews have also been criticised as being time-consuming with regard to both data collection and analysis because they need to be transcribed, coded and possibly translated" (p. 94). Lovelace and Brickman (2013) view is that "quantitative analysis tools such as questionnaire instruments can allow for easier compilation of student responses" (p.12). The students responses can be attached to numerical scores by using the Likert response scale. It is for these reasons that the current researcher finds the quantitative approach to be suitable. More reasons on the researcher's chosen method of data collection will be discussed in section 3.7.

3.4 Research design

According to Kothari (2004), a research design is defined as the master plan or blueprint for the determined methods, structure and strategy of a research to find out alternative tools to solve the problems and to minimise the variances. In other words, a research design refers to the overall strategy to be undertaken by the researcher in an aim to answer the research question/s with regards to the procedures to be used for collecting, analysing, interpreting and reporting the data of the study (Creswell & Plano Clark, 2007). According to Mouton (1996), "the main function of a research design is to enable the researcher to anticipate what the appropriate research decisions are likely to be, and to maximise the validity of the eventual results" (p. 107). Therefore, the chosen "research design should be scientifically grounded, trustworthy and reliable" (Lacobucci & Churchill, 2010, p. 58).

A research design plan can be quantitative and/or qualitative. According to McMillan & Schumacher (1993), a *quantitative research design* adopts the positivism paradigm. While there are many types of quantitative research designs, experimental and non-experimental research designs are known to be the most frequently used. *Experimental research design* is the most common type of quantitative research design. The research design uses a scientific approach whereby the researcher manipulates the level of independent variables, while measuring the dependent variables in a controlled environment. The researcher would collect the data to either support or reject the hypothesis which is tested in the research study. Experimental research designs are powerful techniques for evaluating the cause and effect of relationships between variables. On the other hand, *non-experimental research* design focuses on the researcher observing and analysing the research problem without manipulating any variable. Here the researcher does not have any control over the natural setting of the population.

Two types of non-experimental research design include the correlational research design and the descriptive research design. Similar to the experimental research design, the *correctional research design* involves the researcher observing or measuring two or more variables in order to establish a relationship between the variables. However, in contrast to the correctional research design, the *descriptive research design* aims to describe the characteristics of the population or phenomenon being studied. According to Huczynski and Buchana (1991), a descriptive research design is needed when the researcher wishes to describe, clarify or explain the phenomenon with its inner relationships and properties. Lastly, quantitative research design is more focused on establishing answers to the *what, where* and *when* pertaining to the phenomenon in question.

A *qualitative research design* "is an inquiry process of understanding based on distinct methodological traditions of inquiry that explore a social or human problem. The researcher builds a complex, holistic picture, analyses words, reports detailed views of sampled population and conducts the study in a natural setting" (Creswell, 1998, p. 15). In other words, qualitative research designs are carried out to gain a rich, detailed understanding of a particular phenomenon based on first-hand experience. Unlike a quantitative research design, a qualitative research design is more concerned with establishing answers to the *whys* and *how's* of the phenomenon in question. Due to this, qualitative research designs are often subjective, as opposed to the quantitative research design which is more objective.

The mixed method approach consists of a mixture of quantitative and qualitative research designs. There are four types of mixed method designs which include: exploratory, explanatory, embedded and the triangulation. The *exploratory research design,* as suggested by the name, deals with exploring the phenomenon by defining the problem and gaining additional information on the topic, more especially if there are a few or no previous studies to refer too. Methods such as in-depth interviews, focus groups and projective techniques are used to explore the research problem and hypotheses (Austin & Sutto, 2014).

The explanatory research design, "sets to out explain and account for the descriptive information" (Boru, 2018). According to Baserville and Pries-Heje (2010), while descriptive studies may seek to answer *what* type of questions, explanatory design on the other hand seeks to answer *why* and *how* type of questions to find the causes and reasons for the phenomenon. Experiments are the most popular primary data collection methods which are used in this design.

Embedded research design is a mixed method design approach in which one data set provides a supportive, secondary role in a study-based primary on the other type data (Creswell, Plano Clark, Gutmann & Hanson, 2003). According to the same researcher, embedded mixed-method design includes collecting data using quantitative and qualitative methods, with one set of data playing a supplementary role within the overall design. The use of the both quantitative and qualitative approaches would be to seek to answer different research questions in the study.

The *triangulation research designs* are used to obtain two different, but complementary data sets that both answer the same research question (Morse, 1991). This would mean better understanding of the phenomenon. In simple terms, triangulation involves examining a phenomenon from different perspectives, using different methods and techniques (Laws & Harper 2003). The intention of using this design will be to bring the strengths of using quantitative methods together with the strengths of using qualitative methods in order to strengthen the integrity of the study.

One of the most characteristic advantages of using mixed methods approach is the possibility of triangulation (Hughes, Sharrock & Martin, 2016). The primary advantage for using a triangulation, mixed-method design lies with validating the results of the study by using a variety of methods and techniques. According to Johnston (2014), if both quantitative and qualitative methods leads to the same conclusion, the researcher can surely be confident of their findings. The results will truly reflect what is happening in reality, and not just reflect the method used to collect and analyse data. However, according to Jick (1979), the one drawback of using triangulation design is the lack of uniform methodology for applying triangulation. Hence, the use of triangulation design in research often fails to explain the methods and techniques adequately used to combine the results.

In addition, Creswell (2003), reports that the triangulation design is also known for its one-phase design which allows researchers to implement both quantitative and qualitative methods during the same timeframe. The single -phase timing is the reason why the triangulation design is also referred to as the "concurrent triangulation design", meaning the data can be collected and analysed concurrently by using both quantitative and qualitative methods separately, as indicated in Figure 3.1.

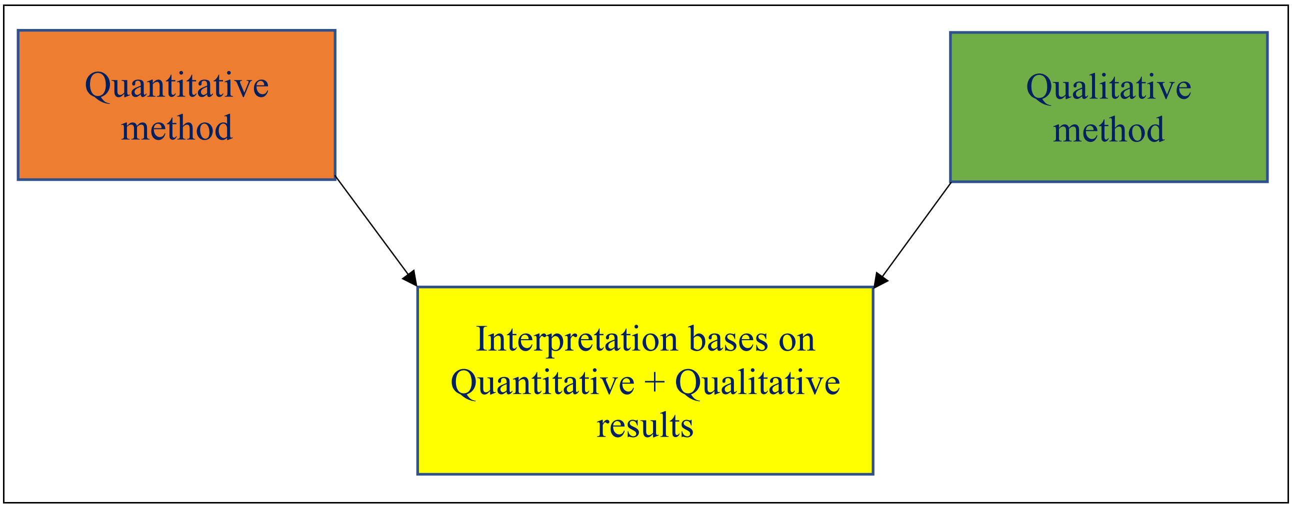


Figure 3.1 The Triangulation design.

A quantitative research design, particularly the descriptive research design was selected for the purposes of the current study, as it is grounded on the ideology of the positivism paradigm. The descriptive research design is an appropriate choice for the current study as the research design is suitable for studies that aim is to identify frequencies of the phenomenon in question. According to Robson (2011), the descriptive research will portray an accurate profile of the sampled population in question. Additionally, the descriptive research design has the potential to providing answers to the two research questions of the current study. Furthermore, this research design also will enable the researcher to answer research questions as objectively and accurately as possible (Kerlinger and Lee, 2000).

3.5 Sampling method

In the case current study, two sampling methods are available for use i.e. the probability sampling and the non-probability sampling.

3.5.1 Probability sampling

According to Showkat and Parveen (2017), probability sampling is a sampling method that uses random selection to select its sample. Consequently, each sample would have an equal probability of being chosen, therefore providing a more reprehensive sample. Some examples of probability sampling methods include *simple random sampling*. This type of sampling completely depends on random methods of sampling such as tossing a coin or throwing a dice, such that each element or combination has an equal probability of being chosen (Showkat & Parveen, 2017). In *systematic random sampling,* this type of sampling samples its members from a larger population randomly, with subsequent members being selected at fixed intervals (Elfil & Negida, 2017). Lastly, *cluster sampling* first divides the population into clusters, and samples are selected randomly from each of the clusters (Showkat & Parveen, 2017).

3.5.2 Non-probability sampling

Unlike probability sampling, non-probability sampling is established on the notion that the researcher would select the sample based on the subjective judgement of the researcher. Non-probability sampling uses non-randomised methods to select its sample, however findings obtained through this type of sampling often lack generalisability (Showkat & Parveen, 2017).

Examples of some of non-probability sampling methods include: *convenience sampling* which is when "the researcher prefers participants as per their own convenience" (Showkat & Parveen, 2017, p.7). *Purposive sampling* relies on the judgement of the researcher on whether the participants meet the requirements needed to answer the research question. Lastly, *snowball sampling* is a non-probability sampling method that samples a population at various stages of the study by selecting further participants from among their acquaintances (Showkat & Parveen, 2017).

3.6 Sampling description

In attempt to answer the two research questions, the sampling process was done in two phases concurrently with each phase aimed at answering one of the research questions.

3.6.1 Phase one: exploring the role played by the mother tongue (first language) in interpreting ERs

The participants in the current research study were selected through purposive sampling. A group of 1st year molecular biology students were selected based upon the notion that they meet the requirements stated in the research question. This type of sampling method was based on the chosen populations considerable variation in demographics such as age, gender, race and language. The variation in the demographics allowed the researcher to gain greater insight into the possible factors that could be affecting how students interpret ERs, thus constructing a robust view of the research question at hand. Consequently, the variation in the demographics of the chosen population enhanced the reliability of study, and thus the results of study can be generalised to the whole population.

The sample comprised of 107 1st year university molecular biology students from culturally, diverse background at a university in South Africa. The chosen university was selected due to the reason that the institution is a contact university that offers molecular biology to students from diverse backgrounds, including offering placement to those who speak diverse languages. The institution was selected through convenience sampling, as the high number of 1st year university molecular biology students that participated in the study was fairly representative of 1st year molecular biology students at large. Even though convenience sampling is not highly recommended by most researchers, the variation in the demographics among 1st year university molecular biology students allowed the researcher to identify a wide range of factors beyond the research question, such as gender. These could be the possible factors that could affect how students interpret ERs that are used in molecular biology, thus making the study more valid. The biographical information of the participants such as the age, gender, educational background, mother tongue language and whether or not the participants learned mRNA in their mother tongue will be presented in Table 4.1.

3.6.2 Phase two: investigating the nature of VSs which are required by students to interpret ERs

ERs used in students' science textbooks signify a tool that students can use to interact with the different levels of abstraction which are used in molecular biology (Offerdahl et al. 2017). It is the same levels of abstraction that are used by lecturers to present information in the formative and summative assessments. Hence, by analysing the different levels of abstractions used in the assessments, the current researcher would be able to identify the nature of VSs that lecturers require 1st year university molecular biology students to have at this level, more especially when learning about mRNA translation.

To investigate the nature of VSs to process ERs about mRNA translation, the researcher purposefully sampled 12 end-of the year, 1st year molecular biology examination papers from two South African universities. The molecular biology examination papers consisted of 1st year cell and molecular biology modules from the one university, and a 1st year molecular biology module from the other university as shown in Table 3.1. Ethical clearance to publish the examination papers from the two universities were not obtained, thus the reason they are not included in the appendices.

Table 3.1 End-of the year 1st year molecular biology examination papers collected from two South African universities with their specific examination dates

Examination papers collected	Module	Date of the examination
1. A1 - Assessment 1	Cell and molecular biology	2015
2. A2 - Assessment 2	Cell and molecular biology	2012
3. A3 - Assessment 3	Cell and molecular biology	2013
4. A4 - Assessment 4	Molecular biology	2015
5. A5 - Assessment 5	Molecular biology	2013
6. A6 - Assessment 6	Cell and molecular biology	2017
7. A7 - Assessment 7	Molecular biology	2017
8. A8 - Assessment 8	Cell and molecular biology	2016
9. A9 - Assessment 9	Molecular biology	2016
10. A10 - Assessment 10	Cell and molecular biology	2018
11. A11 - Assessment 11	Molecular biology	2011
12. A12 - Assessment 12	Molecular biology	2012

3.7 Data collection

According to Kabir (2016), the concept of data collection involves the gathering and measuring of information based on the variables of interest in a research study in order to answer the research question/s. While methods of data collect may differ across disciplines, the goal for all methods of data collection methods is to "capture quality evidence that then translates to rich data analysis and allows the building of convincing and credible answer/s to question/s that have been posed" (Kabir, 2016, p. 202).

There are different methods used to collect data, of which all fall into two categories, i.e. primary and secondary data (Douglas, 2015). According to Ajayi (2017), primary data is data collected for the first time; it is factual and original. Secondary data is data that has been produced by others. It is not original as it is just the analysis and interpretation of primary data. Sources of primary data include collection of data through surveys, questionnaires, observations, experiments, personal interviews etc. which are all involved processes and provides real-time data. Whereas, secondary data involves data collection from government publications, websites, books, journal articles, internal records etc., which all relates to the past. The process of obtaining this type of data tends to be a rapid and easy.

Since the research has adopted the mixed method approach, this means that both quantitative and qualitative data collection methods were explored in the current study. There are a variety of data collection methods in quantitative and qualitative research approaches; however, only a few were explored. Only primary data was collected in the study, as all the data was collected from first-hand experience by the researcher.

3.7.1 Quantitative data collection methods

Strauss and Corby, 1990 regard quantitative research methods as methods where the findings of the study are obtained through the use of statistical means. According to Hoepfl (1997), the use of quantitative data collection methods aims to "seek casual determination, prediction and generalization of findings" (p. 48). The two prime methods of data collection when adopting the quantitative approach are experimental and non-experimental methods.

Kabir (2016) states that there are three types of experiments used in science research. The first type of experiments is the *laboratory controlled experiments.* These types of experiments are conducted in well-controlled environments and thus accurate measurements are possible (Kabir, 2016). The second type of experiments are the *field experiments* which are done in the everyday environment of the participants; however, the researcher would still be able to manipulate the independent variable, but in a real-life setting (Kabir, 2016). Lastly, there are the *natural experiments*. Similar to the field experiments, the natural experiments are done in the everyday environment; however, the researcher has no control over the variables in the real life.

On the other hand, non-experiment methods include survey methods and content analysis. According to Kabir (2016), *survey methods* "provides a means of measuring a population's characteristics, self-reported and observed behaviour, awareness of programs, attitudes or opinions and needs" (p. 224). Survey methods are particularly useful in research studies where the research phenomena is not necessarily measurable or observable (Bowling, 1997). Surveys and questionnaires as instruments of collecting data in a research study are usually thought to be one and the same; however, that is not the case. According to Schofiled and Forrester-Knauss (2013), surveys are a descriptive method which are commonly used to ask the participants a series of questions in a standard manner so that the participants responses maybe quantified and analysed statistically. While questionnaires are considered to be a specific type of survey which is made up of a structured series of questions. Unlike surveys, "questionnaires usually have a highly standardised response options so that the data can easily be analysed and compared" (Schofiled and Forrester-Knauss, 2013, p. 200).

Coe and Scacco (2017) state that *quantitative content analysis* "is a research method in which features of textual, visual or aural material are systematically categorized and recorded so that they can be analysed" (p. 348). Content analysis can be labelled either as quantitative or qualitative, with quantitative content analysis solely focusing on quantifying the occurrences of the research phenomena, while qualitative content analysis focuses on interpreting and understanding the content.

3.7.2 Qualitative data collection methods

According to Gill, Stewart, Treasure & Chadwick (2008), frequently used qualitative research methods includes in-depth interviews, textual or visual content analysis (e.g. from document, books or videos) and focused groups, to name a few. Similar to quantitative content analysis, *document analysis* is when a researcher reviews, evaluates and interprets a document to give voice and meaning to the content of the document around the research topic (Bowen, 2009). *Interview* involves asking questions and getting answers from 6 to 12 participants of the study in order to answer the research question. Interviews vary from individual face-to-face interviews and group face-to-face interviews (Kabir, 2016). Lastly, according to Kabir (2016), *focus groups* discussions are regarded as "an in-depth field method that brings together a small homogenous group to discuss a topic based upon the research study agenda" (p. 221). The main purpose of this method is to use social dynamics of a certain group, with the help of a facilitator, to encourage participants to disclose their opinion or reasons for their behaviour with regards to the research topic.

3.7.3 Phase one: Exploring the role played by mother tongue language in interpreting ERs

a) Instrument design and structure

With regards to the adopted mixed method approach for the current study, data were collected quantitatively for phase one, with the use of a survey-based method in attempt to address the above stated research question. The researcher used an online questionnaire as an instrument to collect data from the participants of the study.

With the world facing the coronavirus disease (Covid-19) pandemic, the current researcher was faced with the challenge of collecting data from the target population due to the Covid-19 lockdown in South Africa. The researcher's initial plan was to collect data using the traditional pencil and paper questionnaire method; however, with the students observing the lockdown period from their homes, the researcher had to find alternative ways of collecting data from the students. With the contact lecture sessions suspended, it would be impossible for the researcher to collect data from students with the initial idea of pencil and paper questionnaires. Therefore, an online- questionnaire was the obvious choice.

An online- questionnaire was a convenient choice as this way of gathering information from students resulted in the entire process of data collection being cost effective and time saving for the researcher (Lefever, Dal & Matthiasdottir, 2007). One other advantage that researchers point out about the use of an online questionnaires is that it "protects against the loss of data and also simplifies the transfer of data for data analysis" (Carbonaro & Bainbridge, 2000, p. 393). The current researcher is aware of the limitations and difficulties of using an online questionnaire.

Even though only a few studies have reported on the reliability of an online questionnaire, one factor influencing the reliability of a questionnaire is its response rate (Lefever, Dal & Matthiasdottir, 2006). According to Comley (2002), factors that could affect the response rate of a questionnaire include the style of the first stage of the questionnaire; this would either grab the respondent's attention or leave the respondent uninterested. To guarantee high response rate and high-quality data, the researcher ensured the purpose of the questionnaire was clearly defined on the invitation letter and was kept short, simple and focused. Additionally, the choice for using closed ended questions, meant giving the respondents specific choices, which would make it easy for them to complete the question. Lastly, the questionnaire was pre-tested with a few friends and family members to find glitches and unexpected question interpretations.

However, with the challenge faced by the tertiary institutions to supply their students with data to access the curriculum, the researcher had to think out of the box and find a platform that was somehow zero-rated, meaning it would not require students to use their own data to complete the questionnaire. With most of the systems used for creating surveys not being zero-rated, Google forms seemed like the ideal platform for launching the questionnaire. Google forms provides a platform for creating and conducting closed, online surveys. This platform is known to use very little data when accessing features on the system. To test how much data the platform would charge off the participants' data account when completing the questionnaire, five respondents (all with different mobile networks were e.g. Vodacom, MTN, Telkom, Cell C, Virgin mobile), were invited to complete the questionnaire through their WhatsApp on their mobiles. This resulted in all the respondents reporting that no data was consumed in completing the questionnaire, meaning that their data balance remained unchanged; however, for one to access the questionnaire they were required to have a positive data account.

A two-part online questionnaire was employed, and the questionnaire was in English. The first part of the questionnaire (Question 1 to 5) was based on retrieving students' demographics, such as the age, gender, educational background and the mother tongue they spoke in. Aside from the demographic questions, students were asked to indicate whether they had learned mRNA translation in their mother tongue language. The second part (Question 6-20) of the questionnaire was based on a study done by Al-Mashikhi, Al-Mahrooqi and Denman (2014). It featured a five-point Likert response scale, with response options ranging from strongly disagree, disagree, neutral, agree and strongly agree. The items used in the questionnaire were designed to investigate the attitudes of 1st year university molecular biology students towards mother tongue language instruction and how it affects their interpretation of ERs used to explain mRNA translation. The items were grouped as items (6-8) aimed to discover the participants' attitudes towards the importance of using English as a medium of instruction. While the next two items (9-10) were designed to investigate students' attitudes towards using their mother tongue language as the medium of instruction. The effects of English proficiency on student's ability to interpret visuals was investigated with items (11, 12 and 13). Students' understanding of ERs used when learning about mRNA translation was covered in item (14-16). Lastly, matters such as the instrumental motivation for using mother tongue language as medium of instruction was covered in the last three items (17-19) (a copy of the questionnaire can be found in Appendix A). The items in each group contained questions of similar nature, but were worded differently. The questions were shuffled, ensuring that they were located in different parts of the questionnaire. This eliminates order bias to improve the questionnaire responses.

b) Validity and reliability of the instrument

To ensure the trustworthiness of methods used in a quantitative study, validity and reliability are concepts deemed to warrantee the accuracy and consistency of the research instrument (Bolarnwa, 2015). According to Kimberlin and Wintersein (2008), the evidence of validity and reliability are prerequisites to ensuring the integrity, quality and trustworthiness of a research instrument. Validity and reliability can increase the transparency and decrease the researchers' bias of the data collection instrument. Therefore, establishing validity and reliability in research is crucial to ensure that the obtained data is accurate, and that the methodology used to obtain the data is replicable (Mohajan, 2017). While validity requires the instrument to be reliable, the reverse does not hold as an instrument can be reliable without being valid (Kimberlin & Winterstein, 2008). More on how the reliability and validity of the study was assessed will be discussed with each research approach.

In a quantitative study, validity is said to assess the extent to which an instrument measures what it was designed to measure (Robson, 2011). There are four major types of validity i.e. content validity, face validity, construct validity and criterion validity (Ghazali, 2016). In measuring face validity of the online-questionnaire, face validity was employed. Face validity is simply looking on the surface of the test instrument and deciding if the instrument is valid or not. Face validity is considered a basic and minimum index of content validity (Mohajan, 2017). Face validity seeks to express validity of an instrument through the involvement of experts in the field of interest, looking at the items in the questionnaires and agreeing or disagreeing that the test instrument is valid or not (Sangoseni, Hellman & Hill, 2013). Face validity is said to be the simplest method to validate an instrument. Since the reviewer only needs to glance through the items, this makes face validity less time consuming than the other validity measures. However, what may be valid to one expert may not be so for another expert, thus making face validity subjective. To overcome this drawback, a panel of experts were employed to review the questionnaire instrument items. Research suggest using a panel of five to eight experts. The panel consisted of one microbiologist, one (Master of Arts)

M.A in linguistics graduate, one (Doctor of Philosophy) PhD biotechnology student, one Grade 6 English language teacher, one Grade 12 Life Science teacher. The use of experts from different fields in the panel was to minimise the extent of bias among the experts (Mnguni et al., 2016). Nonetheless, the current researcher is aware that face validity is not the most sophisticated and most reliable, and thus cannot be trusted as the only form of validity measure.

Another measure of validity used to ensure the validity of the online-questionnaire was content validity. While some researchers may find it unnecessary to report this type of validity, reporting content validity in one's research is extremely important. Content validity looks at the instrument to see whether it appropriately covers all the domains that it should cover with respect to the variables of the study (Heale & Twycross, 2015). This means whether the instrument covers all the content of the construct it is supposed to measure. Yaghmale (2003) believes that content validity can be established in two stages: development (Table 3.2) and judgement stage (Table 3.3). To establish both stages of validity, the current researcher used the following method of validation: the use of the same panel of experts to critique the instrument.

The development stage deals with how the instrument was designed. In this case, the Grade 6 English language teacher was given the questionnaire to check the size of the font, correct use of the language and clarity of the item questions (Fraenkel &Wallen, 2003).

Table 3.2 First criteria for measuring content validity.

Development stage where one member of the panel of experts was given the questionnaire to check on the design and clarity of the questionnaire.

Expert feedback
1. Font -size, type and colour corrected *2. Language and grammar corrected*

The judgement stage involves the use of professional experts to examine the degree to which the instrument was designed to measure the construct. Based on the study done by Yaghmale (2003), a modified 4-point rating scale with questions from Mnguni (2007) was used to rate each item based on its relevance, clarity, simplicity and ambiguity. Table 3.3 was developed and given to two members of the panel of experts i.e. the microbiologist and the M.A in linguistics graduate to scrutinise each item and comment on its legitimacy and appropriateness (Mnguni, 2007) in answering the research questions.

Table 3.3 Second criteria for measuring content validity.

Judgement stage: A modified 4-point rating scale, aimed at rating each item of the questionnaire based on its relevance, clarity, simplicity and ambiguity was given to two members of the panel of experts to indicate why the item had to be included, removed or changed.

4-point rating scale	Questions	Experts feedback
1. Relevance	The terminology used in the item questions were similar to those used in the 1st year molecular biology. The items are helping to address the research questions	The terminology on mRNA translation is relevant for 1st year university Molecular Biology students. Items removed/deleted were due to the issue of redundancy
2. Clarity	The questions are clear and are easy to understand	Modifications were made to make the questions a bit clearer
3. Simplicity	The item questions are simple and easy to follow	Questions are short, simple and to the point
4. Ambiguity	The item questions are not ambiguous	The use of the word “visuals” as opposed to “visual images “was suggested by the experts, as they found it confusing using different terms that actually mean the same thing

To further provide evidence of the online-questionnaire's content validity, content validity index (CVI) was determined to support the validity of the questionnaire (Yuosoff, 2019). CVI is mostly determined in quantitative studies (Shi, Mo & Sun, 2012). The current study followed content validation procedure by Yuosoff (2019). Several studies (Hadie et al., 2017; Ozair et al., 2017) support the use of the procedure in quantifying content validity of an instruments.

The first step in establishing the content validity was to prepare the content validation form for the experts to rate the items based on their relevance to the variables that are being assessed as shown in Table 3.4. All 14 items were rated on a 4-point rating scale by 4 experts. This type of rating scale is recommended for individual items, which is ideal for the current study. The content validation form was sent by email with clear instructions being provided, and no physical meetings were held. The degree of relevance as follows:

1= the item is not relevant to the measured domain

2= the item is somewhat relevant to the measured domain

3= the item is quite relevant to the measured domain

4= the item is highly relevant to the measured domain

Table 3.4 Relevance rating scale given to the experts depicting the layout for content validation form with the domains being investigated along with the items representing the domain.

Domains along with their corresponding items	*Domain 1: The importance of using English as medium of instruction*			*Domain 2: The importance of using English as medium of instruction*		*Domain 3: The effect of English proficiency on students' ability to interpret visual images.*			*Domain 4: Students' understanding of visual images used when learning about mRNA translation.*			*Domain 5: Instrumental motivation for using mother tongue language as medium of instruction.*		
	Item 6	Item 7	Item 8	Item 9	Item 10	Item 11	Item 12	Item 13	Item 14	Item 15	Item 16	Item 17	Item 18	Item 19
Not relevant	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Somewhat relevant	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Quite relevant	1	0	0	0	0	1	1	0	0	0	0	0	0	0
Highly relevant	3	4	4	4	4	3	3	4	4	4	4	4	4	4

Prior to calculating the CVI, the relevance rating of each item rated by the experts was recorded as shown in Table 3.5. Items with the rating of 3 or 4 meant that they were relevant and would have the relevance rating of 1, while items with the rating of 1 or 2 would be considered as irrelevant and would have the relevance rating of 0.

CVI is defined as the proportion of content experts rating the items with the relevance rating of 1, meaning the item had a rating of 3 or 4 on the 4-point rating scale (Yuosoff, 2019). The CVI for each item was calculated using the following formula (Equation 3.1):

$$\text{CVI} = \frac{\text{Number of experts giving rathing of 3 or 4}}{\text{number of panel experts}} \qquad \textit{Equation } 3.1$$

Table 3.5 CVI values for each item given by the experts.

Item	CVI
Item 6	1
Item 7	1
Item 8	1
Item 9	1
Item 10	1
Item 11	1
Item 12	1
Item 13	1
Item 14	1
Item 15	1
Item 16	1
Item 17	1
Item 18	1
Item 19	1

According to Yuosoff, (2019), the acceptable CVI values depends on the number of experts on the panel. For two experts, the acceptable CVI value is at least 0.80, while for three to five experts the acceptable CVI value is 1, and for six to eight experts the acceptable CVI value has to be least high than 0.83. Since all items in the current study have CVI values of 1, all items were considered to be content valid.

Reliability on the other hand, refers to the degree to which the results obtained by certain procedures and measurements can be followed by a number of different researchers and still be replicated. Reliability ensures that the measurement used in the study is without bias from the researcher, and that there is consistency in the method used (Ali and Yusof, 2011). Mohajan (2017) strongly believes that in a quantitative study a research instrument can only be considered reliable if the same results of the study are consistent when the same method is replicated and applied to the same sample, under the same conditions, however different circumstances.

Estimating reliability is a crucial step in research. It is mainly concerned with assessing the following three attributes i.e. equivalence, stability and consistency of the instrument (Drost, 2015). Although calculating the exact value of reliability is not possible, reliability can be estimated using the following two types of measures i.e. internal and external reliability (Heale & Twycross, 2015). External reliability methods assess consistency overtime (test-retest reliability) and across different researchers (inter-rater reliability). While internal reliability focuses on assessing consistency between items across the instrument (split-half reliability and Cronbach's α), meaning that it measures how well some the items measures the variables in the study (Heale & Twycross, 2015). Internal reliability may sound a bit too similar to content validity; however, the difference between the two is that content validity looks at the test instrument as a whole to see whether the instrument measures the construct it intends to measure, while internal reliability looks at whether each item within the test instrument measures the construct it intends to measure.

While test-retest reliability involves giving the same participants the same instrument on two different occasions and later comparing the results to see if there is any correlation, this approach would not be ideal for the current study due to the time constraints. On the other hand, split-half reliability would be an ideal method for the current study, as it is convenient, and the results can easily be obtained over a short period of time. This approach works by combining one half of the test instrument to form one measure and the other half forming the second new measure (Drost, 2015). The correlations are calculated by comparing the two measures. Strong correlations indicate high reliability (Heale & Twycross, 2015). However, the one disadvantage with using the split-half method is that the reliability estimate obtained using any random splitting of items is likely to be different from the reliability estimate items which are split in another way.

When one considers calculating the internal consistency reliability of an instrument, an ideal approach would be using the Cronbach's α. This approach is used to assess internal consistency. Cronbach's α not only computes the correlation between the items of an instrument, but goes further to computing the average intercorrelation among the items. Just like the split-half reliability, Cronbach's α is a simple and convenient way to estimate the extent to which all the items in a test instrument are all measuring the same construct, and also how the items correlate with each other. Nevertheless, unlike split-half reliability, Cronbach's α

works well even with instruments containing a small number of items, this is why it is most widely used as an approach for measuring internal consistency (Tavakol & Dennick, 2011).

Cronbach's α is known to be an ideal approach for most types of scales, including Likert-type scales. Since the online-questionnaire in the current study used a 5- Likert-type scale items, Gilem and Gilem (2003) concluded in their research study that when using Likert-type scale, it is highly imperative to estimate internal consistency reliability with a method like Cronbach's α. Due to the uni-dimensionalilty of the items in the study, this makes Cronbach's α an ideal method to determine internal consistency.

This formula uses a summated scale, as Cronbach's α does not provide reliable estimates for single items (Adeniran, 2019). The value of Cronbach's α is always between 0.0 and 1.0, with 0.0 indicating no consistency and 1.0 indicating perfect consistency. The acceptable range is between 0.70 and 1.0. The resulting Cronbach α was 0.85, which indicates that the 14 items in the questionnaire have a high covariance, meaning that the items in the questionnaire measure the same underlying concept. In the current study Cronbach's α was calculated using an online software on https://www.wessa.net.

c) Data collection

Before the research instrument could be distributed to the target participants, the researcher had to make certain to coincide with ethical care. Ethical clearance (Appendix B) was obtained from the University of South Africa's College of Education Ethics Review Committee to ensure that the research will be conducted in responsible and ethical manner, while minimising the risks to humans and ensuring the research leads to beneficial outcomes. In order for the researcher to obtain ethical clearance, the researcher was required to provide details of the research study in relation to the ethical protection of the participants (Mnguni, 2007). Details such as the nature the study, research questions, the nature of the participants, sample size, ethical protection of the participants (Mnguni, 2007) and the approach to be undertaken to answer the research question were required. The ethics committee looked into the above mention parts of the study to ensure that the study will be conducted in manner which will protect the dignity, rights and safety of the participants.

The researcher also had to briefly motivate how the study was to benefit the participants and the following points were indicated in the application:

1. The benefit of the study entailed promoting the VL competency among students especially molecular biology students. This is because molecular biology classrooms are known to require extensive use of ERs to better understand the complex and abstract phenomena in the curriculum.

2. Also, to evaluate and improve student teaching and learning in science education by assisting educators and curriculum designers in making informed decisions with regards to incorporating teaching VSs in the curriculum.

Concerning the ethical protection of the participants, ethical approval from the University of the Free State's Senate Research Ethics Committee was applied for, and approval was granted (Appendix C). The research proposal, ethical clearance certificate from the University of South Africa, along with the informed consent were reviewed in the application process. The informed consent clearly indicated that only students older than 18 years of age were permitted to participate in the study. The researcher also had to clearly indicate that those participating in the study were not exposed to any risk, and that the study was not to affect the students' academic program and that students were also able to withdraw from the study at any time and without giving a reason.

In order to protect the confidentiality of the students, data was collected anonymously without the participants having to give personal information or personal identities such as the name of participant's, date of birth or email address. The questions of the study were also of non-sensitive nature, as there were no questions related to personal experience or psychological well-being of the participants.

The data collection instrument was then distributed to the participants by the researcher. This was an email invitation letter containing the link to the online questionnaire, along with information about the research which was then sent to the lecturer who was responsible for the 1st year molecular biology module. According to Ritter and Sue (2007), invitation letters are the first point of contact with the potential respondent, as a result invitation letters should be intriguing, simple, short and to the point. Invitation letters are letters that invites potential participants to participate in the study and also contain information about the study such as denoting the nature of the study, the voluntary nature of the participation and the risks of the study. If the potential participants agreed to participate to the study, their consent would be given by clicking on the link to start the questionnaire. However, the participant could also email the researcher to request for the full version of the informed consent.

The lecturer then posted the invitation letter containing the link to the questionnaire on the 1st year molecular biology module blackboard page. This was located on the university's website page which can only be accessed by the target population. The one disadvantage of placing invitation letters on websites includes the possibility of obtaining a very low rate of response. However, this was overcome by the high number of 1st year university molecular biology students that accessed the blackboard daily to view their study material, which in turn increased the chances of meeting the target sample population. Following the data collection process, all responses of the respondents on the online survey tool were deleted and stored on a password protected computer.

3.7.4 Phase two: investigating the nature of VSs which are required by students to interpret ERs

a) Instrument design and structure

Data for this phase was also collected quantitatively with the use of content analysis method. The instrument used to collect data in this phase was based on a previously validated study done by Offerdahl et al. (2017), and the data was collected based on the following two variables being studied in the current study:

1. Nature of ERs used in the assessment items used to explain mRNA translation.

2. VSs required by students in the assessment items used to assess mRNA translation.

Content analysis is considered a method used to determine specific patterns of words, images or concepts give within the text or a set of documents. Content analysis can be quantitative as well as qualitative. According to Vitouladiti (2014), quantitative content analysis focuses only upon counting and measuring the frequency of specific phrases, words, images, concepts or subjects. While qualitative content analysis on the other hand, focuses on interpreting and understanding of a particular type of content by analysing the relationship between the concepts.

Despite the fact that quantitative content analysis is a time consuming which requires manual coding of large quantities of concepts, the method can also be beneficial for researchers as the method allows for analysis of communicative tools without the need of participants. This enables the researcher to collect data at any time and place at their convenience.. The other advantage of using content analysis is that it follows a systematic strategy that can be easily be replicated by other researchers, generating results with high reliability. It is for this reason that the researcher decided upon using a previously validated instrument developed by Offerdahl et al. (2017) where ERs used in general chemistry, introductory biology, cell biology and biochemistry assessments where coded and characterised, based on the developed taxonomy of visual abstraction. Therefore, allowing the researcher to replicate the steps taken by the researcher and produce reliable results.

To determine the assessment items, only the assessments with items that included ERs on mRNA translation were used for analysis as shown Table 3.6. From the 12-assessment sampled by the researcher, only 8 of the assessments contained items on mRNA translation and were thus considered applicable for the current study.

Table 3.6 Number of formative and summative assessments and total assessments items collected from the 1st year university molecular biology curriculum.

Assessments collected	Assessment items	Items with ERs on mRNA translation
13. A1 - Assessment 1	73	3 (4.1%)
14. A2 - Assessment 2	56	4 (7.1%)
15. A3 - Assessment 3	64	7 (10.9%)
16. A4 - Assessment 4	45	4 (8.9%)
17. A5 - Assessment 5	22	4 (18.1%)
18. A6 - Assessment 6	44	1 (2.3%)
19. A7 - Assessment 7	66	3 (4.5%)
20. A8 - Assessment 8	58	3 (5.1%)
21. A9 - Assessment 9	41	-
22. A10 - Assessment 10	42	-
23. A11 - Assessment 11	63	-
24. A12 - Assessment 12	39	-

b) Data collection

Quantitative coding is a common practise for analysing information where non-numerical data which is characterised into groups and assigned numerical codes so as to easily analyse the data using statistical techniques. Once the coding process is done, researchers often move to "identifying themes in their data and to try attach some significance to their findings by offering explanations, drawing conclusions and extrapolating examples" (Rossman & Rallis, 2012, p. 282). The assessment items selected from the sampled assessments were coded following a two-part process:

i. Determining ERs used in molecular biology when learning about mRNA translation

As denoted in section 2.8, in order to determine the nature of ERs used in the assessment items to assess mRNA translation, the taxonomy for characterising the levels of abstraction in instructional representation was used to classify the ERs either as symbolic, schematic, graphic, cartoon form or as realistic images (Offerdahl et al., 2017), as shown in Table 3.7. The ERs were assigned one or more levels of abstraction by indicating their presence or absence as shown in Table 3.7. For each example of the levels of abstraction e.g. chemical structure, use of arrows, photographs, chart etc., a value of 1 was assigned for its presence and "0" for its absence. The total number of levels of abstraction was calculated to equal the sum of the abstraction types or examples e.g. chemical structure + chemical equation + scientific symbol + one -two or three-letter abbreviation of named = *Symbolic*.

Table 3.7 Sample of the coding system used to analyse the ERs to determine the levels of abstraction in the assessment items.

Levels of abstractions **informed by Offerdahl et al. (2017).**	**Score for the nature of ER used in the assessment item recorded by the coder**
1. Symbolic	2
1.1 Chemical structure	1
1.2 Chemical equation	0
1.3 Scientific symbol	0
1.4 One -two or three-letter abbreviation of named	1
2. Schematic	1
2.1 Use of line	0
2.2 Use of arrows	1
3. Graphs	0
3.1 Curves	0
3.2 Bars	0
3.3 Plotted	0
3.4 Chart	0
4. Realistic images	0
4.1 Micrographs	0
4.2 Plotted	0
5. Cartoons	1
5.1 Cartoons	1

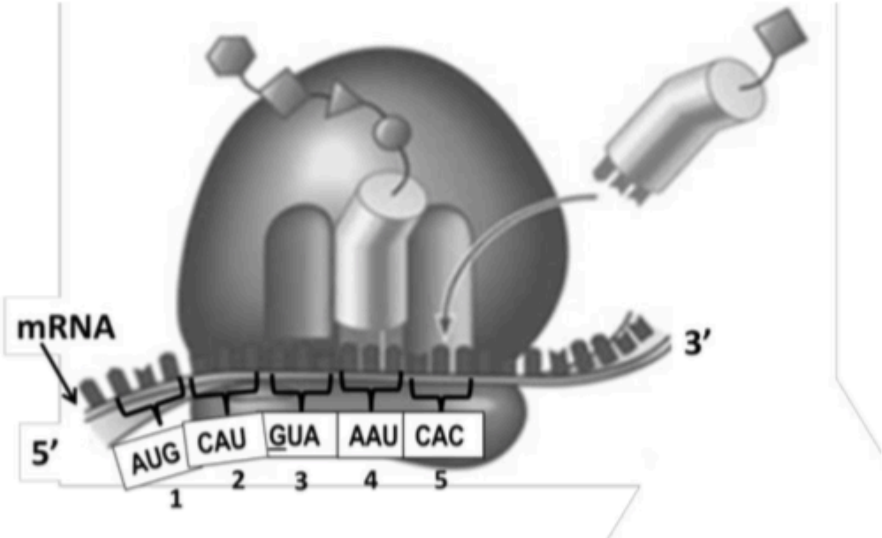


Figure 3.2: Example of an ER analysed to determine *the nature of ERs used in the assessment items used to explain mRNA translation* (The image is adopted from A3).

ii. Determining VSs which are required by molecular biology students when learning about mRNA translation

To determine the VSs required by students in the assessment items to assess mRNA translation, Table 2.2 (Mnguni et al., 2016) was used as a checklist to identify which of the VSs are required to process ERs that are used to explain mRNA translation. Figure 3.3 shows a sample item question which was analysed using Table 2.2 as a check list to identify the type of VSs required by students to effectively interpret the assessment item. The VSs were recorded by indicating their presence as shown in Table 3.8. Each presence of VSs was assigned a value of 1 and the total number of VSs were calculated by equating the sum of all the present VSs.

Table 3.8 Sample of the coding system used to analyse the ERs to determine the required VSs in the assessment items.

VSs code	VS*s* informed by Mnguni et al. (2016)	Score for VSs required in the assessment item
T01	Analyse; interpret; assess; evaluate; examine; investigate	0
T02	Arrange; order; organise; classify	0
T03	Compare, relate	0
T04	Complete	0
T05	Critique	0
T06	Depth perception; recognition of depth cues	0
T07	Describe; discuss; explain	1
T08	Discriminate	0
T09	Find; locate	0
T10	Focus	0
T11	Ground perception	0
T12	Illustrate; sketch	0
T13	Imagine	0
T14	Infer; predict	0
T15	Judge	0
T16	Manipulate; mental rotation; recognise orientation; recognition; identify; identify shapes	1
T17	Outline	0
T18	Perceive luminance; identify colours	0
T19	Perceive motion	0
T20	Perceive speed	0
T21	Perceive texture	0
T22	Propose; develop; formulate; devise; construct; create; produce; invent	0
T23	Recall; retrieve	1
T24	Use	0
Total VSs		**3**

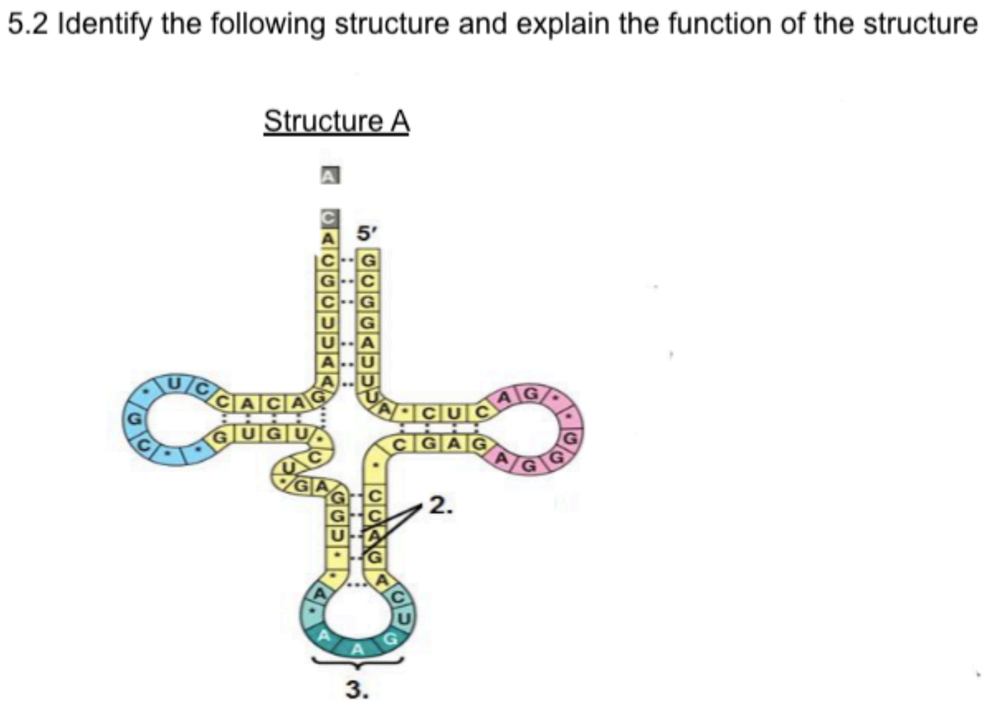


Figure 3.3 Example of an ER analysed to determine *VSs required by students in the assessment items used to assess mRNA translation (*The image is adopted from A2).

c) Validity and reliability instrument

One limitation of using the quantitative content analysis method to collect data is that the method’s level of subjective interpretation can affect the reliability and validity of the study. Therefore, to ensure reliability of content analysis of the assessment items, each item was analysed by two coders and a percentage agreement between the two coders was calculated before discussions as seen in Table 3.9 (Offerdahl et al., 2017). It is a statistics measure used for many years to simply measure the inter-rater reliability among data collectors.

According to McHugh (2012), to obtain the measure of percentage agreement in the current study, the researcher created a matrix in which the columns represented the two coders and the rows represented the variables which are the nature of ERs used in the assessment items translation and the VSs required by 1st year university molecular biology students to effectively interpret ERs used when learning about mRNA translation. The cells in the matrix contain the scores given by coders for each variable from each assessment item. To obtain the percentage agreement between the coders, the researcher subtracted the coder 2 scores from coder 1 scores and counted the number of zeros that resulted. By dividing the number of zero with the number of variables and multiplying by a hundred, provides the percentage agreement between the raters. Table 3.9 exabits the percentage agreement between the raters for all the assessments with values ranging from 64%-81%, indicating strong agreement between the raters, while 82% -100% indicates an almost perfect agreement between the raters (McHugh, 2012).

Table 3.9 Inter-rater reliability – percentage agreement between coders.

Assessment type	**Total agreement (%)**
A1	88.4%
A2	90.7%
A3	93.0%
A4	100%
A5	97.6%
A6	100%
A7	95.3%
A8	72.2%

3.8 Data analysis

Analysing data is considered as a process of characterising, classifying and summarising the data that was obtained through the methods of data collection in order to answer the research question. This section presents a description of how that data was collected through the use of quantitative data collection methods. The analysis of data was carried out in two phases. Phase one dealt with how the questionnaires were analysed. Phase two was based on how the data was collected through the use of quantitative content analysis.

According to Shah and Madden (2007), for statistical analysis there are two types of data that are recognised: *parametric data* which refers to a set of data that is usually measured and assumes a normal distribution. Kataike, Kulaba and Gellynck (2015) refers to this data as measured data. Measured datasets are continuous and may take up any real value. While *non-parametric data* refers to a set of data that is either counted or ranked, and assumes a non-normal distribution. Kataike, Kulaba and Gellynck (2015) refers to this type of data as discretedata. Discrete data are whole numbers and they usually present a count of objects.

Two categories of statistics are recognised i.e. *inferential statistics* which is statistics that takes the data collected from the sample population and makes inferences about the larger population. However, because inferential statistics takes the data from a portion (sample population) of the larger population and makes inferences or generalisations about the larger population, the researcher needs to have absolute confidence that the sampled population truly reflects the entire population. On the other hand, *descriptive statistics* simply describes the sampled population, without making any inferences or generalising about the larger population. In descriptive statistics, the data collected is simply summarised through graphs and tables.

Collected data was analysed descriptively in terms of measuring frequency, central tendency and a measure of variability for both phases. Central tendency measures the mean, median and mode, while a measure for variability includes measuring standard deviation or variance. This form of analysis was chosen by the researcher. Descriptive analysis gives the researcher an idea on the distribution of the data set by providing estimates and summaries which can be arranged as graphs and tables.

3.8.1 Measures of central tendency

According to Manikandan (2011), a measure of central tendency is regarded as the statistical summary that represents the centre point in a distribution. This means that the measure indicates where most of the values in a distribution fall. There are three major types of measures of central tendency.

The mean is the most common of all the three measures of central tendency. According to Krishnaswamy (2006), the mean is the arithmetic average of all the values within a distribution. To calculate the mean of distribution, all the values of a distribution are added and divided by the total number of the values. According to Manikandan (2011), the mean does not always locate the centre of the data accurately. In symmetrical distribution, the mean locates the centre accurately. However, if the distribution is a bit skewed the mean can miss the mark a bit.

The median is known as the middle value. One can say that the median is the score found at the midpoint or middle of the distribution and splits the data set in half. In order to find the median of a data set, the data has to be ordered first from smallest to largest, and the data point that has equal amount of values below it and above it is regarded as the median. However, locating the median varies when the data set has an even number of values. If there is even numbers in the data set, then the median would be the average of the two numbers found in the middle.

The mode is the most frequently occurring value in the data set. According to Manikandan (2011), in a bar chart the mode is the highest bar. The mode is the better value to estimate for the data set, as it measures the frequency of both the ERs and VSs in the assessment items in attempt to answer the research question. For categorical data observed in the current study, the mode was determined by looking at the category with the highest frequency.

3.8.2 Measure of variability

The most common measure of variability is the standard deviation. According to Davis (2011), standard deviation is a measure of how spread out your dataset is. Standard deviation typically tells you the standard distance of each score from the mean. It is known as the most robust and widely used measure of dispersion. When data scores are closely clustered around the mean, this means that the standard deviation is small and the dataset is said to have a normal distribution. While a relatively larger standard deviation is presented by a wide spread dataset score.

In reference to the data obtained from the assessment items in the current study, Kader and Perry (2007) stipulates that statistics textbooks rarely provide a measure of variability for categorical data, as there is usually an impression that there is no measurement of variability for the categorical variable. This is based on notion that the mean and median don't apply with categorical variables, as they would make no sense. However, Reilly (2017) suggests that it would make better sense to actually measure residuals as to how far an individual value is from the typical value and to quantify variation as the average of a residual. Kader and Perry (2007) recommend the measurement of *unalikeability*, of which Kaplan (2009) regards as a simple measure of variation in a simple two-level categorical variable especially for categorical variables. Kader and Perry (2007) defines *unalikeability* as the frequency of observations that differ from one another".

3.8.3 Phase one: Exploring the role played by the mother tongue language in interpreting ERs

Part one of the online questionnaire was used to retrieve the participants demographics such as the age, gender, educational background and mother tongue language. All these variables were subjected to frequency counts, meaning that the participants responses for each individual question were added together to find the highest frequency occurrence. The quantified frequency counts were presented in Chapter 4 as a percentage and in graphical form. The relevant measure of central tendency and measure of variability was established to determine the central point of the data and how widely spread the data is, respectively.

With regards to the dichotomous question where the participants were asked to indicate *whether or not they had learned mRNA translation in their mother tongue language*, the variable was subjected to a frequency count, where the question was scored by assigning a 1 for every *YES* response and *0* for every *NO* response. Scoring allows for non-numerical data to be assigned a value, thus enabling the researcher to analyse data using statistical analysis. The data was then presented in a graphical form.

Part two of the online-questionnaire featured a five-point Likert response scale to determine the central tendency and variability of the data. Each response option were assigned values from *1* to *5*, with *strongly disagree* assigned *1*, *disagree* assigned *2*, *neutral* assigned *3*, *agree* assigned *4* and *strongly agree* assigned *5*. The total scores were subjected to frequency counts and presented as percentages and in a graphical form. The relevant measure of central tendency and measure of variability was established to determine the central point of the data and how spread that data is, respectively.

3.8.4 Phase two: investigating the nature of VSs which are required by students to interpret ERs

Once the assessment items were analysed by coding and were characterised on the basis of identifying the nature of the ERs used in the assessment items, and also once the identification of VSs required by 1st year university students to effectively interpret ERs on mRNA translation was completed, the data gathered was subjected to frequency counts. This means that for identifying the nature of the ERs, the number of times the levels of abstractions appeared throughout all the assessment items were added together to find the highest frequency occurrence. Similarly, the number of times the VSs appeared in the assessment items were also calculated to find the highest frequency occurrence. The frequency distribution of the two variables were presented in tabular form along with their percentages and graphic form.

3.9 Conclusion

This section summaries the types of methods and instruments used in the current study to collect data from the sampled participants, and highlighted the methods used to analyse the collected data in order to answer the research questions (Figure 3.2):

1. With investigating the nature of VSs required by 1st year university molecular biology students to effectively interpret ERs when learning about mRNA translation, an online-questionnaire was used as the instrument to collect data. The online-questionnaire was validated using face validity and content validity and CVI calculated to provide more evidence for the content validity. For insuring internal reliability of the instrument, Cronbach's α was determined.

2. With exploring the extent to which the mother tongue language affected how students interpreted ERs used in explaining mRNA translation, quantitative content analysis was employed to analyse the sampled assessment items, where coding was used to characterise the data and determine the occurrence of the variables. In order to establish the internal reliability of the coding process which is usually known to be subjective, percentage agreement was determined between the coders to establish the level of agreement by coders in coding the variables.

3.9.1 Summary of methods used in this study

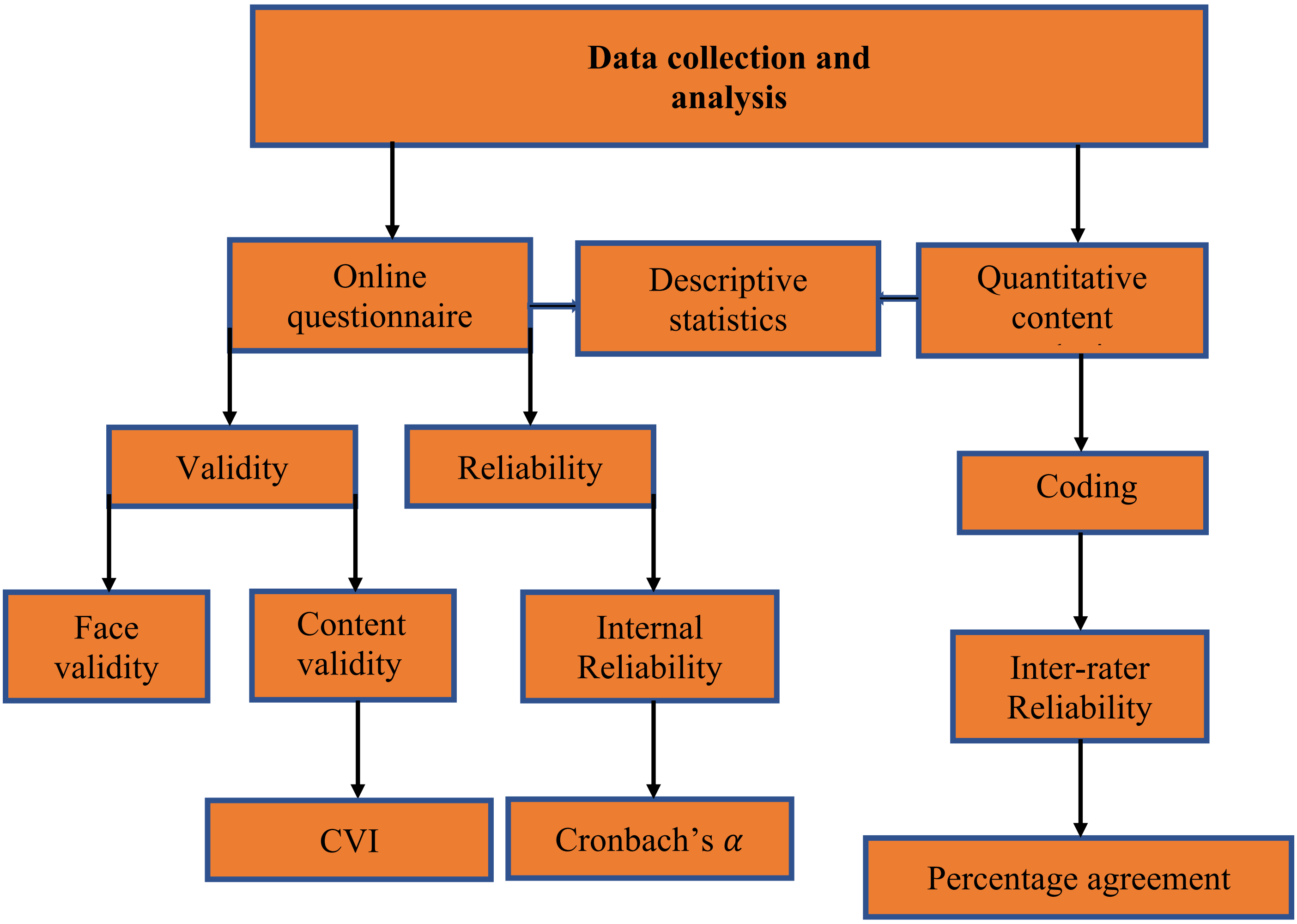


Figure 3.4: A summary of the research design followed in the current study

CHAPTER 4: RESULTS PRESENTATION

4.1. Introduction

This chapter presents the results of data collected and analysed as discussed in Chapter 3. Data presentation forms an integral part of research and refers to the organisation of data in the form of tables, graphs, charts, text or numerical values. Adding the visual aspects to the data makes the data collected easier to understand.

4.2 Frequency counts: Exploring the role played by mother tongue language in interpreting ERs

Among the 110 participants that accessed the online-questionnaire, only 107 (97.2%) completed the entire questionnaire. The participants responses to the questions were quantified and presented as a frequency and percentage.

The first part of the questionnaire (Question 1 to 5) sought to identify the participants based on their age, gender, educational background, mother tongue language and whether or not the participants learned mRNA in their mother tongue. Table 4.1 shows the age categories of the participants who took part in completing the questionnaires. Only the age category ranging from 18-39 years completed the questionnaires, with no participants aging 40 years and older. The age category 18-20 years had the highest frequency count of 67.3%. The gender distribution of the participants that took part in completing the questionnaire is also demonstrated, 72.9% of the participants that took part in the study were females, 28% were males and 0.9% of the participants preferred not to say what their gender was.

Table 4.1 also depicts the participants highest education qualification, with 83.2% of the participants holding a National Senior Certificate (Grade 12) as their highest qualification. The other participants either completed a diploma, bachelor's or honour's degree, with no participant holding a master's degree or any higher qualification. When it came to the participants mother tongue language, there was a large variation in the mother tongue language spoken among participants. The largest group of participants indicated Afrikaans to be their mother tongue language with a percentage of 20.6%. isiXhosa and Sesotho both featured at 15.9%, respectively. isiZulu was the fourth most represented mother tongue language with percentage of 14%. The other represented languages with the least percentages were Sepedi, TshiVenda, XiTsonga, siSwati, English and SeTswana. No other languages were represented along with the Ndebele language. Lastly, 25.2% of students who spoke both English or Afrikaans stated that they learned about mRNA translation in their mother tongue language, while the rest did not.

Table 4.1 Biographical information: Questions 1-5.

Variables		**Frequency**	**Percentage (%)**
1. Age	*18-20*	72	67.3
	21-29	25	23.4
	30-39	10	9.3
	40-49	0	0
	50-59	0	0
	60 or older	0	0
	Total	**107**	**100**
2. Gender	*Female*	78	72.9
	Male	28	26.2
	Prefer not to say	1	0.9
	Other	0	0
	Total	**107**	**100**
3. Highest education qualification	Grade 12	89	83.2
	Diploma	9	8.4
	Bachelor's degree	8	7.5
	Honor's degree	1	0.9
	Honour's degree	1	0.9
	Master's degree or Higher	0	0
	Total	**107**	**100**
4. Mother tongue language	isiZulu	15	14
	isiXhosa	17	15.9

	SePedi	9	8.4
	SeSotho	17	15.9
	isiNdebele	0	0
	TshiVenda	3	2.8
	XiTsonga	3	2.8
	siSwati	6	5.6
	Afrikaans	22	20.6
	English	3	2.8
	SeTswana	12	11.2
	Other	0	0
	Total	**107**	**100**
5. I learned about mRNA translation in my mother tongue language	Yes	27	25.2
	No	80	74.8
	Total	**107**	**100**

The second part (Questions 6-20) of the questionnaire were designed to investigate the attitudes of 1st year university molecular biology students towards mother tongue instruction, and how it affects their interpretation of ERs used to explain mRNA translation. Table 4.2 focused on Question 6- 8 of the questionnaires which were items related to students' attitudes towards the importance of using English as medium of instruction.

In response to Question 6, about 85% of the participants preferred English to be the language of instruction. Similar results were observed in Question 7, where about 80% participants preferred being taught molecular biology in English. Equally, the participants responses to Question 8 indicated that over 85% of the participants disagreed with the item, thus preferring that English be used as the medium of instruction.

Table 4.2 The importance of using English as medium of instruction: Questions 6-8.

Variables		**Frequency**	**Percentage (%)**
6. It is important that I study molecular biology in English	Strongly disagree	6	5.6
	Disagree	5	4.7
	Neutral	5	4.7
	Agree	47	43.9
	Strongly agree	44	41.1
	Total	**107**	**100**
7. It is appropriate to use English as the medium of instruction	Strongly disagree	6	5.6
	Disagree	6	5.6
	Neutral	10	9.3
	Agree	51	47.7
	Strongly agree	34	31.8
	Total	**107**	**100**
8. I feel that English should not be used as the medium of instruction	Strongly disagree	42	39.3
	Disagree	49	45.8
	Neutral	4	3.7
	Agree	7	6.5
	Strongly agree	5	4.7
	Total	**107**	**100**

Table 4.3 summaries the participants attitudes towards using their mother tongue language as the medium of instruction. In response to Question 9, the item had over 63.5% participants not preferring to use their mother tongue language as the medium of instruction when learning about mRNA translation. Similarly, over 60% of the participants disagreed with Question 10 which states that "mother tongue language would be more effective as the medium of instruction in the study of molecular biology than English".

Table 4.3 Students' attitudes towards using their mother tongue language as the medium of instruction: Questions 9-10

Variables		**Frequency**	**Percentage (%)**
9. I prefer using my mother tongue language as the medium of instruction to learn about mRNA translation	Strongly disagree	29	27.1
	Disagree	39	36.4
	Neutral	7	6.5
	Agree	20	18.8
	Strongly agree	12	11.2
	Total	**107**	**100**
10. My mother tongue language would be more effective as the medium of instruction in the study of molecular biology than English	Strongly disagree	31	29
	Disagree	34	31.8
	Neutral	5	4.7
	Agree	26	24.2
	Strongly agree	11	10.3
	Total	**107**	**100**

Table 4.4 depicts the effects of English proficiency on the student's ability to interpret visuals. The above table demonstrates that over 61% of the participants actually agreed with the item in Question 11 that "English proficiency affects students' ability to master visual interpretation as used in the learning about mRNA translation images correctly," while only 24 % of the participants disagreed. The item in Question 12 which indicates that "it is unfair to use English as a medium of instruction for all students because students with higher English proficiency may be able to master interpreting visual images correctly" had 43% of the participants' disagreeing with the items. However, 39.3% of the participants agreed with the item, while the rest were neutral. Lastly, the item in Question 13 which states that "it is necessary that I study molecular biology in English even if my English proficiency is low" had 72% of the participants agreeing with the item.

Table 4.4 The effect of English proficiency on students' ability to interpret visual images: Questions 11-13.

Variables		Frequency	Percentage (%)
11. Having low English proficiency affects students' ability to master visual interpretation as used in the learning about mRNA translation images correctly	Strongly disagree	8	7.5
	Disagree	18	16.8
	Neutral	15	14
	Agree	40	37.4
	Strongly agree	26	24.3
	Total	**107**	**100**
12. It is unfair to use English as a medium of instruction for all students because students with higher English proficiency may be able to master interpreting visual images correctly	Strongly disagree	16	14.9
	Disagree	30	28
	Neutral	19	17.8
	Agree	31	29
	Strongly agree	11	10.3
	Total	**107**	**100**
13. It is necessary that I study molecular biology in English even if my English proficiency is low	Strongly disagree	7	6.5
	Disagree	12	11.2
	Neutral	11	10.3
	Agree	57	53.3
	Strongly agree	20	18.7
	Total	**107**	**100**

Table 4.5 presents students' understanding of ERs used when learning about mRNA translation. In response to the item in Question 14, over 81% of the participants reported not to have any difficulty in understanding the images used to explain mRNA translation, if the textbook is in English. Question 15 reported around 60% of the participants not believing that they would spend less time to study for test in molecular biology, if the course was taught in their mother tongue. Lastly, Question 16's item "learning about mRNA translation in English is time consuming as it takes me a while to interpret the images used in the textbook", had about 66% of the sampled participants disagreeing with the statement.

Table 4.5 Students' understanding of visual images used when learning about mRNA translation: Questions 14-16.

Variables		**Frequency**	**Percentage (%)**
14. When I study mRNA translation in the textbook in English, I find it difficult to understand the images used	Strongly disagree	30	28
	Disagree	57	53
	Neutral	8	7.5
	Agree	10	9.3
	Strongly agree	2	1.9
	Total	**107**	**100**
15. I would spend less time to study for test in molecular biology if the course was taught in my mother tonguage language	Strongly disagree	30	28.1
	Disagree	34	31.8
	Neutral	9	8.4
	Agree	27	25.2
	Strongly agree	7	6.5
	Total	**107**	**100**
16. Learning about mRNA translation in English is time consuming as it takes me a while to interpret the images used in the textbook	Strongly disagree	28	26.2
	Disagree	42	39.3
	Neutral	6	5.6
	Agree	27	25.2
	Strongly agree	4	3.7
	Total	**107**	**100**

In conclusion, Table 4.6 revealed the "participants instrumental motivation for using their mother tongue language as a medium of instruction." The results indicated that over 51% of the participants agreed with the item in Question 17 which stated that "studying molecular biology in my home language enhances my visual skills.' In response to Question 18 "learning about mRNA translation in my mother tongue language makes me understand it better" 44.9% disagreed, 43.9% agreed and 11.2% of the participants were neutral. Lastly, the item in Question 19 indicated that 76.6% of the participants disagreed with the item "My ability to interpret images/visuals used when learning about mRNA translation is affected negatively when I study molecular biology in English" while 15.9% of the participants agreed with the item and the rest remained neutral.

Table 4.6 Instrumental motivation for using mother tongue language as medium of instruction: Questions 17-19.

Variables		**Frequency**	**Percentage (%)**
17. Studying molecular biology in my home language enhances my visual skills	Strongly disagree	22	20.6
	Disagree	33	30.8
	Neutral	9	8.4
	Agree	35	32.7
	Strongly agree	8	7.5
	Total	**107**	**100**
18. Learning about mRNA translation in my mother tonguage language makes me understand it better	Strongly disagree	20	18.7
	Disagree	28	26.2
	Neutral	12	11.1
	Agree	32	30
	Strongly agree	15	14
	Total	**107**	**100**
19. My ability to interpret images / visuals used when learning about mRNA translation is affected negatively when I study molecular biology in English	Strongly disagree	29	27.1
	Disagree	53	49.5
	Neutral	8	7.5
	Agree	15	14
	Strongly agree	2	1.9
	Total	**107**	**100**

4.3 Frequency counts: Nature of ERs used in the assessment items used to explain mRNA translation

More than a quarter (26%) of all the assessment items which were collected had contained at least one ER on mRNA translation. There was a notable variety of levels of abstractions that were reinforced by the assessments. However, none of the assessment items contained either graphs or realistic/ images.

Table 4.7 and Figure 4.1 demonstrates the frequency distribution and percentages of assessment items containing ERs used to assess mRNA translation. Figure 4.1 illustrates levels of abstraction that are reinforced in all the 8 selected assessments, respectively. A1 was moderately loaded with 66.7% of schematic representations and a low percentage (33.3%) for both symbolic representations and cartoon representations. A2 comprised of 50% symbolic representations and schematic representations, while cartoons lagged behind on 25%. A3 was highly loaded with symbolic representations and schematic representations (85.7% and 71.4%, respectively). However, the assessment had no cartoons on mRNA translation. A4 comprised of a third (75%) of symbolic representations, half (50%) of schematic representations and a quarter (25%) of cartoons, while A5 and A6 were heavily laden with 100% of symbolic.

No schematic representations were observed in A5, even though A6 contained a high number of schematic representations at 100%. A5 also comprised of 25% cartoons, with A6 having no cartoons depicting mRNA translation. Lastly, A7 and A8 both contained schematic representations with 66.7%, and the same amount was seen with cartoons and symbolic representations in A7 and A8, respectively. However, A8 had no cartoons present. It was evident that the mode for this data set is the symbolic representation as they appeared most frequently across all the assessment items.

Table 4.7 Frequency of the ERs used throughout the assessment items.

Nature of ERs	Number of times the ER appears in the assessment items
1. *Symbolic*	20
2. *Schematic*	18
3. *Cartoons*	6
4. *Graphs*	0
5. *Realistic images*	0
Total	44

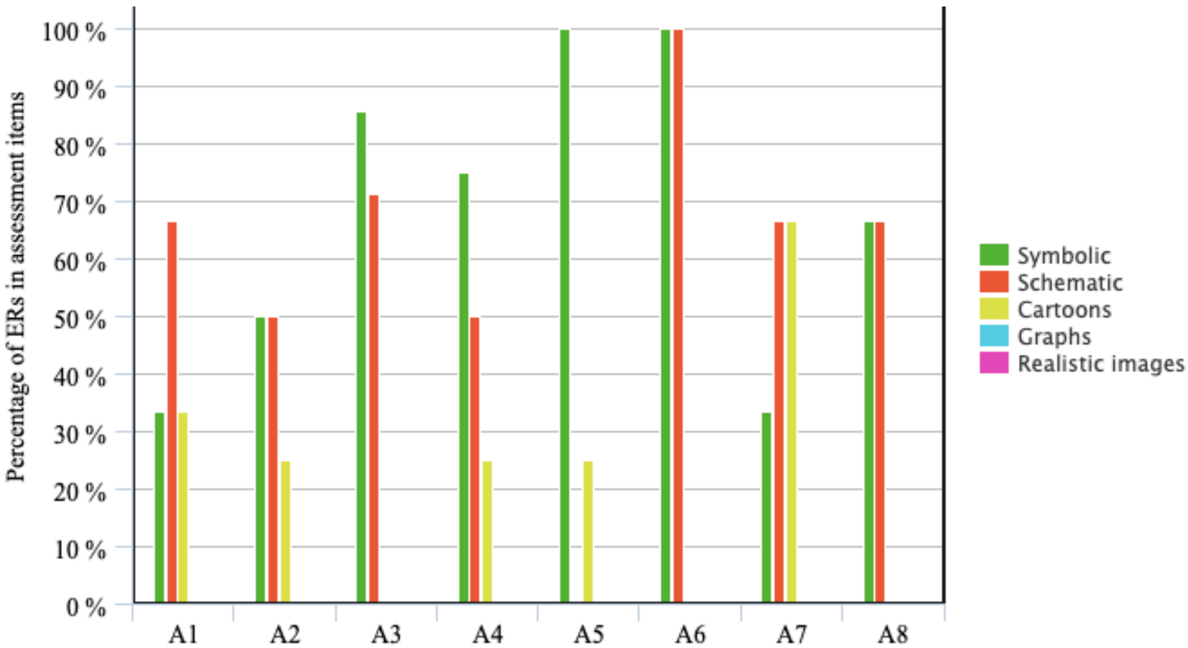


Figure 4.1 Percentages of coded items containing ERs on mRNA translation, demonstrating each level of abstraction within each assessment. (Bars do not total 100, as some assessment items were multimodal and therefore double coded (Offerdahl & Arneson, 2017).

4.4 Frequency counts: VSs required by students in the assessment items used to assess mRNA translation

Table 4.8 and Figure 4.2 depicted the number of times the VSs were required by 1st year molecular biology students in the 8 assessment items. With regards to the coding process, only the VSs which had the two coders had an agreement on which was to be considered in the analysis. T23 appeared to be the most frequently assessed VS, with the VS being assessed 16 times in the 8 assessments. This VS was also observed to be assessed 5 times in just one assessment (A3).

T01, T16, T24 were the other VS observed to have appeared frequently in the assessment items, with T01 and T24 appearing 11 times and T16 appearing 12 times. T03, T04, T07, T12 had very low frequency based on their appearance in the assessment items, ranging from 1 to 4 times. Lastly T02, T06, T08, T09, T10, T11, T13, T14, T15, T17, T18, T19, T20, T21, T22 were not represented in any of the assessments.

Table 4.8 The number of times VSs required to effectively interpret ERs used in assessing mRNA translation appeared.

VS code	Number of assessments							
	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**
T01	√			√√√	√√√	√	√√	√
T02								
T03		√						
T04		√	√					√
T05			√					
T06								
T07			√√				√√	
T08								
T09								
T10								
T11								
T12				√				
T13								
T14								
T15								
T16			√√√√	√√√	√√	√	√√	
T17								
T18								
T19								
T20								
T21								
T22								
T23	√√√	√√	√√√√√	√√√		√	√√	
T24			√√	√√	√√√√	√	√√	

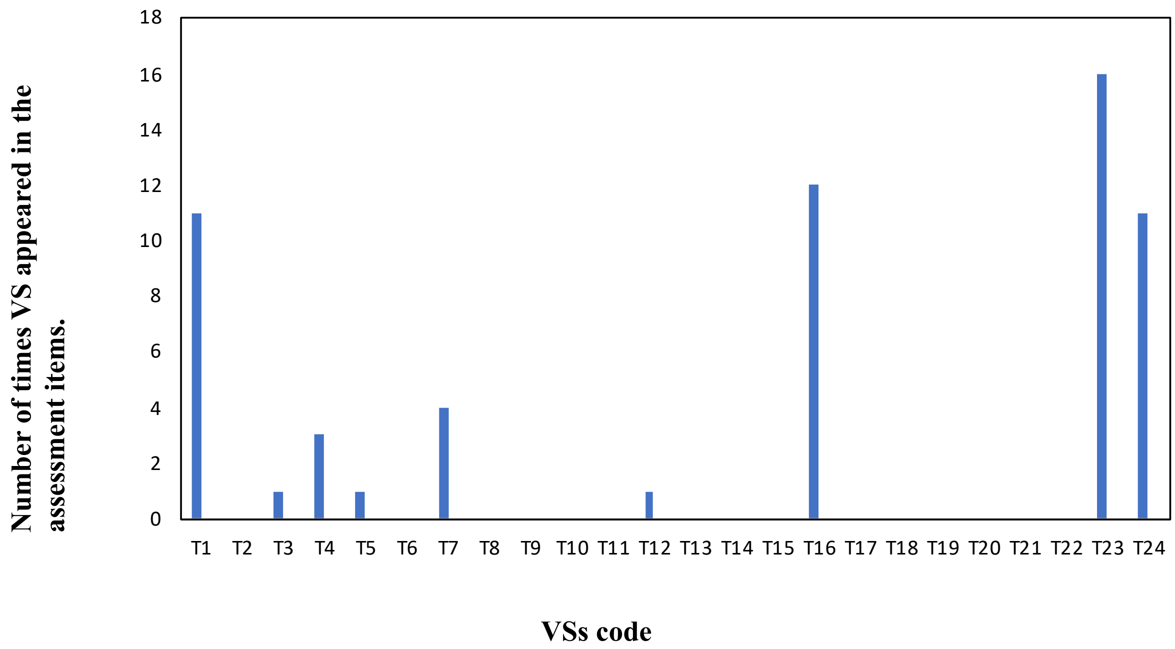


Figure 4.2 Frequency distribution bar graph depicting the number of times the VS required to effectively interpret ERs on mRNA translation appeared in the assessment items.

Table 4.9 reports the mode values of the data set. Symbolic representation is the mode, appearing to be the most frequently assessed level of abstraction with a percentage of 45%. T23 is the VS that was the most frequently assessed VS, with the VS appearing 16 times in the 8 assessments.

Table 4.9 Summary of descriptive Statistics of Measure of Central Tendency (Mode) of the nature of ERs and VSs assessed in the assessment items.

Variable	**Mode**
Nature of ER (level of abstraction)	Symbolic
VSs	T23

4.5 Summary of descriptive statistics for molecular biology student' attitudes towards mother tongue instruction

The study reported a positive attitude in the area of *English as a medium of instruction (Question 6, 7 and 8)*, with the mean value of 2.0 (with 1 representing strongly agree, 3 neutral and 5 strongly disagree) and *SD = 1.24*. In contrast, the students demonstrated a negative attitude in the area of *mother tongue language as a medium of instruction (Question 9* and 10) with the mean value of 3.6 (*SD = 1.39*). For *Questions 11, 12 and 13,* students exhibited a positive attitude in the area on the *effect of English proficiency on the ability to interpret visual images*, reporting a mean value of 2.37 (*SD = 1.22*). Moreover, students displayed a positive attitude in the area of *understanding of visual images used when learning about mRNA translation (Question 14,15 and* 16), with the mean value of 2.3 (*SD = 1.22*). Lastly, *Question 17, 18 and 19* had students indicating a negative attitude in the area of *motivation for using mother tongue language as medium of instruction* as reported a mean value of 4.1 (*SD = 1.27*). Additionally, the students' attitudes towards mother tongue instruction displayed a normal distribution.

4.6 Conclusion

This chapter presented the results of the current research study which were obtained from the online-questionnaire and the quantitative content analysis, and data collection methods. The next chapter (Chapter 5) provides conclusions and recommendations where the current researcher will discuss the findings of the study. Further, Chapter 5 will present the limitations of the research study along with guides to educators on how they can help develop their students' VL skills.

CHAPTER 5: DISCUSSION AND CONCLUSION

5.1. Introduction

This chapter summarises the conclusions and recommendations that emanated from the current study. The researcher begins by providing a summary of the study which is followed by an interpretation and discussion of the findings in the study. Subsequent to this are the direct responses to the research questions. Lastly, this is followed by a conclusion with few recommendations that can be used to improve the study in the future.

5.2 Summary of the study

VSs are required by students to master science. This study presents some insight into which of the aforementioned VSs are necessary for 1st year molecular biology students to possess in order to be able to interpret the ERs used when explaining mRNA translation. Additionally, the current researcher also explored whether language had any impact on the student's ability to effectively interpret ERs that is used to explain mRNA translation. The objectives of this study were to investigate the nature of VSs that are required by 1st year molecular biology students to effectively process and interpret ERs used when learning about mRNA translation. To also explore the extent to which the mother tongue language affects how students interpret ERs that are used in explaining mRNA translation. To answer the first research question, two variables were determined as follow:

Research Question 1: What is the nature of VSs required by 1st year molecular biology students to effectively interpret ERs used when learning about mRNA translation?

a) *Nature of ERs used in the assessment items to explain mRNA translation*

b) *VSs required by students in the assessment items used to assess mRNA translation*

Research Question 2: To what extent does mother tongue language affect how students interpret ERs used in explaining mRNA translation?

5.3 Discussion of the findings

Findings for Research Question 1 - *Nature of ERs used in the assessment items used to explain mRNA translation*

In Chapter 2, the development and importance of visual literacy in science education was discussed in great detail. According to Offerdahl et al. (2017), within the context of molecular biology in particular, ERs frequently incorporate various components "such as discipline-specific graphical and diagrammatic features, varied levels of abstraction, and spatial arrangements of visual elements to convey information"(p. 1).

As already motioned, molecular biology students make extensive use of ERs which are made available through media such as textbooks, simulations, and lecture slides. Similarly, the students are often asked to generate ERs such as schematic models, graphs and diagrams. This provides students with the opportunity to practice, test, and develop their visual literacy skills (Airey and Linder, 2009).

According to Tibell and Rundgren (2010), undergraduate molecular biology textbooks are estimated to have up to 50% of the page space occupied with ERs. Significantly, textbooks provide students with opportunities to interact with the ERs. Additionally, educators tend to also use the same ERs from the textbooks in their lectures slides and classroom activities. Consequently, due to the prominence of ERs in the molecular biology modules, Offerdahl et al. (2017) used undergraduate molecular biology textbook figures "to develop a taxonomy that allows for characterizing five general categories of abstraction used in instructional representation" (p. 2) i.e. symbolic, schematic, graph, cartoon and realistic.

Similarly, Offerdahl and Arneson (2013) deems that extracting meaning from ERs used in molecular biology requires translation across these levels of abstraction (e.g. from graphs to schematic models). In light of the above, Offerdahl and Arneson (2013) analysed molecular biology textbooks and high-profile, scientific journals for the five categories of levels of abstraction to determine the role of textbook figures in developing students' VSs.

Furthermore, in the current study the taxonomy of levels of abstraction (Figure 2.2) was used to start a discussion regarding the extent to which the development of visual literacy skills is supported by instruction within an undergraduate molecular biology curriculum. Additionally, the taxonomy was used to determine the nature of ERs which are used in the molecular biology assessment items used to explain mRNA translation.

After analysing the assessments, the current study's findings indicate symbolic and schematic representations as the two levels of abstractions that are highly reinforced in molecular biology assessments, particularly at 1st year level. The current study's findings corroborated with the findings of Offerdahl et al., (2017) who reported molecular biology assessments to have been heavily laden with symbolic and schematic representations. Nonetheless, Offerdahl et al., (2017) denoted that even though the study contributed greatly to research by providing a taxonomy of visual abstractions that could be useful for educators, the findings verify the notion that students are still not provided with diverse opportunities to gain experience across the various levels of abstraction.

Conversely, the current study found the cartoons to be poorly represented with graphs or realistic images not assessed in any of the assessment items. Similarly, Offerdahl and Arneson (2013) found that molecular biology textbook figures are generally displayed only on a single level of abstraction. Additionally, levels of abstraction that contain quantitative representations such as graphs seemed to have been seldomly represented. Hence, the results suggest that ERs used in traditional instruction lack the complexity necessary to explicitly support the development of VSs.

Findings for Research Question 1 - *VSs required by students in the assessment items used to assess mRNA translation*

As previously discussed, Bloom's taxonomy is widely accepted as a tool for educators to use as a golden standard for determining learning objectives (Mnguni et al., 2016, p. 1) and also increase student learning (Crowe, Dirks & Pat Wenderoth, 2017). Crowe et al. (2017) developed an assessment tool based on Bloom's taxonomy, "to assist science educators to better align their assessments with their teaching activities and to help students enhance their study skills and metacognition" (p.1).

Allen and Tanner (2002) also applied the Bloom's taxonomy to characterise the learning outcomes in science education and how to better assess them. In contrast, Mnguni et al. (2016) used the Blooms taxonomy to characterise the cognitive skills that are innate to VL. According to Mnguni et al. (2016), 24 VSs were developed that were based on the cognitive skills associated with the process of visualisation, while seeking to measure students' VL level. Similar to the current study, Mnguni et al. (2016) aimed to determine the type of "VSs that are required for students to effectively process ERs that are related to biochemistry content" (p. 1) by observing students' interpretation of ERs used in the test instrument.

The findings of the Mnguni et al. (2016) study uncovered students' inability to correctly visualise and interpret some of the ERs that were used in the test instrument. Almost all participating students were not able to perform skills such as *perceive luminance* (code T18), *depth perception* (code T06), *focus* (code T10), *ground perception* (code T11), *outline* (code T17), *propose* (code T22), complete (code T04), *critique* (code T05) and *classify* (code T02), which are all essential VSs required for students to possess at an undergraduate molecular biology level.

However, in contrast to Mnguni et al., (2016) the current findings brought to light how educators and instructional designers still have not taken the development of students' visual literacy skills seriously. This is observed in the study's finding where only the ability to *retrieve* information (code T23), *analyse* (code T01), *identify* (code T16), and *use* (code T24) appeared to be the most reinforced and frequently assessed VS in the curriculum. However, according to Mnguni et al. (2016) "students need to be exposed to more VSs as the more VSs students have the higher they move on the VL scale" (p. 1) . Consequently, with the limited VSs assessed in the molecular biology curriculum, this may be because educators and curriculum designers are not making the development of VSs a priority among molecular biology students.

Additionally, with only the ability *retrieve* or *recall* (code T23) prior knowledge being the most widely assessed VS in 1st year molecular biology assessments, the current researcher wonders whether the ability to retrieve or recall information is an appropriate VS to be reinforced at an undergraduate level. Nonetheless, Glaser (1984) considered prior knowledge to be the area of focus more especially at undergraduate level, as students entering the higher education system come with less developed prior knowledge and thus have not yet been assimilated into the culture of learning at a higher level. Therefore the *recalling* (code T23) prior knowledge VS still needs to be further developed.

Findings for Research Question 2

"While there are many factors involved in delivering quality science education, language is clearly the key to communication and understanding in the classroom" (Benson, 2004, p. 1). This would explain why so many students in Haiti are failing science. The students are taught science in French which is not their mother tongue (Behrmann, 2018). The objective of the research study by Behmann (2018) was to determine if there were differences in performance when students are taught science in their mother tongue called Kreyol as compared to when they are taught in French.

The researchers hypothesized that when students learn science in their mother tongue language, this will increase their efficiency of understanding and enable them to process scientific information which is presented in the science curriculum. The study consisted of two sample groups of Haiti students. "Students in each group (French or Kreyol) were first provided with a grade appropriate-level pre-test. Both groups were then taught the same concept in the language condition to which they were assigned, and lastly both groups were provided a post-test in that same language" (Behrmann, 2018, p. 41)

According to Behrmann (2018), the findings of the study agreed with the hypothesis. The findings exhibited a significant difference between "pre and post-test scores of students who were taught science concepts in Kreyol versus those that were taught in French" (p. 74). The results demonstrated higher performance in science for students that were taught in their mother tongue Kreyol as compared to students that were taught in French.

Furthermore, a similar study to the current study was conducted by Al-Mashiki et al., (2014) who "investigated undergraduate science students' attitudes towards using English as a medium of instruction" (p. 1), as opposed to their mother tongue language which was Arabic. To collect data, students where administered questionnaires. The findings of the current study are similar to the findings by Al-Mashiki et al., (2014) who indicated that the majority of students prefer to study science/molecular biology in English. On the contrary, Mammino (2010) deemed that the use of the mother tongue language in science education will assist students to better comprehend scientific content information. However, Al-Mashiki et al., (2014) reported that the students believed that studying science in English is important and necessary, especially if one intends to further their studies in post-secondary education with the aim of attaining a tertiary qualification. This is because most science tertiary degrees are taught in English.

In contrast to the findings by Behrmann (2018) and Al-Mashiki et al., (2014), the current study reported that the overall participants disagreed with the notion that it is hard to learn science/molecular biology through the English language. The majority of the students also disagreed with the notion that learning about mRNA translation in their mother tonguage language would make them understand it better. Moreover, the current study's findings also indicate that students learning molecular biology in English are not negatively affected, more especially in their ability to interpret ERs used when learning about mRNA.

Therefore, in response to the research question 1, the current researcher rejects the hypothesis that students studying molecular biology in English contributes to the lack of VSs among second language English Speakers, thus preventing students from effectively learning through ERs in molecular biology. Additionally, in response to the research question 2, the researcher found symbolic and schematic representations, along with cartoons as the nature of ERs used to assess mRNA translation at 1st year university level in molecular biology. Moreover, the following VSs: 'retrieve' or 'recall', 'analyse', 'identify' or 'use' were identified as VSs required by students in the assessment items used to assess mRNA translation.

5.4 Conclusions and recommendations

5.4.1 Research summary

The aim of the research has been to contribute towards understanding the nature of VSs that students are required to possess in learning molecular biology at 1st year level. The findings of the study will assist curriculum designers and educators to make informed decisions about how to effectively use ERs in science education and to prioritise the specific VSs that are required at 1st year level. In addition, the study also sought to gain understanding on the role played by using the mother tongue in molecular biology as a medium of instruction. In this regard, the findings will provide instructional designers and educators insight on the use of English as the medium of instruction to second language English speakers in the tertiary institutions in South Africa, particularly in the field of science education.

5.4.2 Limitations

Although the study has contributed some unique findings to literature, the study possessed some limitations. The main limitation was that data was collected from a sample of students who attended a single learning institution. The majority of the participants were Afrikaans speaking females between the age of 18-39 years. This implied that the sampled population was not representative of the variation of the mother tongue languages that would be generally found in a South African tertiary institution. Therefore, Mnguni et al. (2016) recommends that "the instrument be further calibrated through multiple rounds of testing with a broader sample" (p. 8).

5.4.3 Recommendations for further research

Based on the unsatisfactory number of VSs that 1st year university molecular biology students are required to possess, the current study may stimulate further important research questions to improve the understanding of VL. For instance, instructional designers and educators may ask: 'Beside assessments, what other type of opportunities could be provided to students to expose them to a variety of ERs?' Following the classification of the levels of abstraction by Offerdahl et al., (2017), future research could also focus on asking: 'How can educators better reinforce a variety of levels of abstraction in molecular biology?'.

Based on the findings of the study, the current researcher recommends that to improve on students understanding of VL, instructional designers and educators need to make the necessary changes in their practice. This can be done by exposing students to a wide range of tasks containing variety of ERs and by also prioritising the development of the VSs that students require to correctly interpret ERs used in molecular biology in order to "build powerful and integrated mental models of biochemical phenomenon" (Loshe et al.,1991; Schönborn, 2005).

5.4.4 Conclusion

Due to the unsatisfactory number of the nature of VSs that are required by 1st year molecule biology students to effectively interpret ERs used when learning about mRNA translation, the current study encourages educators to prioritise the developments of students' VSs by exposing students to a wide range of levels of abstraction and VSs. This research also supports the notion that "if assessments do not regularly make use of ERs, educators are sending a message to students that visual literacy is unimportant and may inadvertently reinforce erroneous ideas about the role of VL within the molecular biology" (Offerdahl et al., 2017, p. 8).

Therefore, the current researcher concludes that language does indeed affect students' perception of ERs in molecular biology. However, this does not necessarily mean that students should be learning molecular biology in their mother tongue language. In actual fact, the findings of the study exhibited students' "attitudes" towards their preference of English as the medium of instruction in molecular biology. Furthermore, students rejected the notion that learning molecular biology in their mother tongue would enable them to effectively interpret ERs used when learning about mRNA translation.

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7. Appendix

7.1 Appendix A: Participants information sheet and Questionnaire

QUESTIONNAIRE FOR THE STUDY TITLED: ASSESSING VISUALISTION SKILLS OF MOLECULAR BIOLOGY FIRST YEAR STUDENTS IN A LANGUAGE DIVERSE LECTURE ROOM, SOUTH AFRICA

Dear Participant

I would hereby like to invite you to complete a questionnaire for which a link is provided below. I am doing this study as part of obtaining my Masters in Life Science Education.

The questionnaire aims to assess the attitudes of 1st year molecular biology students towards mother tongue instruction in their interpretation of visuals used to explain mRNA translation.

Participants information:

1. **Why am I being invited to participate?** You are invited to be part of the focus group of the study as you fit the demographical group the study aims to investigate.
2. **What is the nature of my participation in the study?** The study involves the participants answering a 3 min questionnaire.
3. **How old should I be to complete the questionnaire?** Only students older than 18 year are permitted to participate in this study
4. **What are the potential benefits of the study?** Improve student teaching and learning in science education by assisting educators and curriculum designers in making informed decisions with regards to incorporating teaching visualisation skills in the curriculum.

5. **Will I receive payment or any incentive for participating in this study?** There will be no remuneration, reimbursement or any incentive for participation in the research.
6. **Has the study received ethical approval?** This study has received written approval from CEDU REC.

Please note that your participation is entirely voluntary and you are free to decline to participate in this questionnaire. The questionnaire is anonymous and response data will only be analysed at aggregate level.

The survey was created through Google forms, which only requires the participants to have a positive data account. NO data was consumed during the testing of the survey.

If you have any questions or concerns about this study, please feel free to contact me at mase.mokhele@gmail.com .

If you are willing to participate and complete the electronic questionnaire, please click on the link below.

https://docs.google.com/forms/d/e/1FAIpQLSfMRz8Hdk_-ZBG7I6K5bwofTvKV7A1C85Jyz3marJAATIITTw/viewform?usp=sf_link

Kindly note the closing date of the survey is Friday, 27 June 2020

Regards

Moleboheng Malekoa Ramulumo.

QUESTIONNAIRE FOR THE STUDY TITLED: ASSESSING VISUALISTION SKILLS OF MOLECULAR BIOLOGY FIRST YEAR STUDENTS IN A LANGUAGE DIVERSE LECTURE ROOM, SOUTH AFRICA

Questionnaire assessing the attitudes of 1st year molecular biology students towards mother tongue instruction in their interpretation of visuals used to explain mRNA translation.

1. Age	18-20	21-29	30-39	40-49	50-59	60 or older

2. Gender	Female	Male	Prefer to say	Other

3. Highest education qualification	Grade 12	Diploma	Bachelor’ s degree	Honour’ s degree	Master’ s degree

4. Home language	Other	Tswana	English	Afrikaans	Swati	Tsonga	Venda	Ndebele	South Sotho	North Sotho	Xhosa	Zulu

5. I learned about mRNA translation in my mother tongue language	Yes	No

	Strongly disagree	**Disagree**	**Neutral**	**Agree**	**Strongly agree**
The importance of using English as medium of instruction					

6. It is important that I study molecular biology in English.					
7. It is appropriate to use English as the medium of instruction in learning about mRNA translation.					
8. I feel that English should not be used as the medium of instruction in the 1st year at university level.					
Students' attitudes towards using their mother tongue as the medium of instruction.					
9. I prefer using my mother tongue as the medium of instruction to learn about mRNA translation.					
10. My mother tongue would be more effective as a medium of instruction in the study of molecular biology than English.					
The effect of English proficiency on students' ability to interpret visual images.					
11. Having low English proficiency affects students' ability to master visual interpretation as used in the learning about mRNA translation images correctly.					
12. It is unfair to use English as a medium of instruction for all students because students with higher English proficiency may be able to master interpreting visual images correctly.					
13. It is necessary that I study molecular biology in English even if my English proficiency is low.					

Students' understanding of visual images used when learning about mRNA translation.					
14. When I study mRNA translation in the textbook in English, I find it difficult to understand the images used.					
15. I would spend less time to study for test in molecular biology if the course was taught in my mother tongue.					
16. Learning about mRNA translation in English is time consuming as it takes me a while to interpret the images used in the textbook.					
Instrumental motivation for using mother tongue as medium of instruction.					
17. Studying molecular biology in my home language enhances my visual skills.					
18. Learning about mRNA translation in my mother tongue makes me understand it better.					
19. My ability to interpret images / visuals used when learning about mRNA translation is affected negatively when I study molecular biology in English.					

……………………………………………………………………………………………

Researcher: Moleboheng Malekoa Ramulumo 7/04/2020

7.2 Appendix B: Ethical clearance from the University of South Africa

UNISA university of south africa

UNISA COLLEGE OF EDUCATION ETHICS REVIEW COMMITTEE

Date: 2019/10/16

Ref: **2019/10/16/51915987/32/MC**
Name: Ms MM Ramulumo
Student No.: 51915987

Dear Ms Ramulumo

Decision: Ethics Approval from 2019/10/16 to 2022/10/16

Researcher(s): Name: Ms MM Ramulumo
E-mail address: Mase.Mokhele@gmail.com
Telephone: +27 76 318 5143

Supervisor(s): Name: Prof LE Mnguni
E-mail address: mngunle@unisa.ac.za
Telephone: +27 12 429 4614

Title of research:

Assessing visualisation skills of molecular biology first year students in a language diverse lecture room, South Africa.

Qualification: M. Ed in Life Science Education

Thank you for the application for research ethics clearance by the UNISA College of Education Ethics Review Committee for the above mentioned research. Ethics approval is granted for the period 2019/10/16 to 2022/10/16.

*The **low risk** application was reviewed by the Ethics Review Committee on 2019/10/16 in compliance with the UNISA Policy on Research Ethics and the Standard Operating Procedure on Research Ethics Risk Assessment.*

The proposed research may now commence with the provisions that:

1. The researcher(s) will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.
2. Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study should be communicated in writing to the UNISA College of Education Ethics Review Committee.

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UNIVERSITEIT VAN DIE VRYSTAAT
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UFS UV

Office of the Vice-Rector: Research and Internationalisation
Kantoor van die Viserektor: Navorsing en Internasionalisering

31-Jan-2020

Dear Ms. Ramulumo Moleboheng

UFS AUTHORITIES APPROVAL

Research Project Title:
Assessing visualisation skills of Molecular biology first year students in a language diverse lecture room, South Africa

This letter serves as confirmation that you have received reciprocal ethical approval from the University of the Free State (UFS). It also confirms approval to collect data from the UFS students and/or staff members.

Kind Regards

PROF RC WITTHUHN
VICE-RECTOR: RESEARCH & INTERNATIONALISATION
CHAIR: SENATE RESEARCH ETHICS COMMITTEE

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