INVESTIGATING BIOLOGY SECONDARY SCHOOL TEACHERS' KNOWLEDGE BASES IN THE TEACHING OF BIOTECHNOLOGY

DOCTOR OF PHILOSOPHY (SCIENCE AND MATHEMATICS EDUCATION) DISSERTATION.

By

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DECLARATION

I, the undersigned, hereby declare that this dissertation is my original work, which has not been submitted to any other institution for similar purposes. Where other people's work has been used, acknowledgements have been made.

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CERTIFICATE OF APPROVAL

The undersigned certify that this dissertation represents the student's work and effort and has been submitted with our approval.

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DEDICATION

This dissertation is dedicated to my parents, my late father, George Ernest Gershom Vakusi who always encouraged me to do this study before I retire, and my late Mother, Mary Nzina Vakusi; to my wife Bridget and son George Junior, for their encouragement and untiring support during the whole period of my study.

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ABSTRACT

This study explored how biology teachers utilise their knowledge bases in teaching biotechnology. It specifically addressed five objectives: understanding the teachers' content knowledge of biotechnology; identifying topic-specific teaching strategies used in biotechnology; examining the teachers' awareness of students' conceptions and learning difficulties in biotechnology; evaluating the methods used by teachers to assess students' understanding of biotechnology concepts; and assessing how teachers integrate the biotechnology curriculum in lesson planning and delivery. Adopting an interpretivist paradigm, the study aimed to capture the teachers' experiences with biotechnology education. The sample consisted of three biology teachers from three schools. Data were collected using a biotechnology test, content representations, interviews, and lesson observations. Document analysis of various curriculum documents was employed to triangulate the data. The findings revealed that the biology teachers had insufficient content knowledge and struggled to connect biotechnology concepts with students' prior learning in genetics and reproduction. Additionally, teachers demonstrated a lack of familiarity with instructional strategies and assessments specific to biotechnology. The study highlighted a reliance on textbooks for content knowledge and teaching strategies, noting that some textbooks lacked illustrations and activities to stimulate critical thinking. Effective teaching of abstract biotechnology concepts requires the proper use of topic-specific PCK components. The study recommends that curriculum developers ensure textbooks include comprehensive content with clear illustrations and activities aligned with the syllabus.

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LIST OF ACRONYMS AND ABBREVIATIONS

AK	Assessment Knowledge
CDSS	Community Day Secondary School
CK	Content Knowledge
CoRe	Content Representation
CoRes	Content Representations
CRK	Curriculum Knowledge
CWED	Central West Education Division
DNA	Deoxyribonucleic acid
DTED	Directorate of Teacher Education and Development
GMO	Genetically Modified Organism
ICT	Information and Communication Technology
INSET	In-service Training
LUANAR	Lilongwe University of Agriculture and Natural Resources
MoE	Ministry of Education
MoEST	Ministry of Education, Science and Technology
MSCE	Malawi School Certificate of Education
NBC	National Board Certification

NRC	Natural Resource College
OTA	Office of Technology Assessment
PCK	Pedagogical Content Knowledge
PCR	Polymerase Chain Reaction
PhD	Doctor of Philosophy
PK	Pedagogical Knowledge
KS	Knowledge of Student
SMASSE	Strengthening of Mathematics and Science Secondary Education
STE	Science, Technology and Engineering
TPIK&S	Teacher Professional Knowledge and Skills
TPKB	Teacher Professional Knowledge Bases
TSPCK	Topic Specific Pedagogical Content Knowledge

CHAPTER ONE

INTRODUCTION

5.1 1.1 Chapter overview

This chapter presents the background for this study, describing the motivation, purpose and significance of this study, the problem that the study sought to address as well as the research questions that guided the study. The chapter further briefly discusses the concepts that were core and relevant to this study, such as student-centred curriculum, SMASSE programme and biotechnology. In the final analysis, the chapter gives a definition of terms used in this study and highlights the organisation and structure of the entire thesis.

5.2 1.2 Background of the study

1.2.1 Student-centred curriculum

Biotechnology was incorporated in the Malawi secondary school Biology curriculum during the Malawi secondary school curriculum review of 2013. The incorporation of biotechnology into the biology curriculum responded to Malawi government's initial goal to design a curriculum that responds to contemporary trends and developments in science and technology.

The effective delivery of the curriculum depends on the ability of teachers, who are its key implementers, to interpret it to the learners and to engage them throughout the process of learning. This implies that successful interpretation of the curriculum and meaningful engagement of learners throughout the process of learning also depends heavily on the teachers' knowledge of the subject matter as well as their awareness and mastery of student-centred methods of lesson delivery (Güler & Çelik, 2018).

The revised curriculum recommended that teachers use student-centred methods in their teaching and assessment as one way of encouraging learners to actively participate in the learning process (MoEST, 2013). Student-centred methods do not only influence learners' active participation in the lesson, but also increase chances that learners will understand what they are learning and be able to recall the knowledge later, apply it to situations and develop desired skillsets based on the imparted knowledge. Effective use of student-centred methods and techniques to teach learners such complex topics as biotechnology requires teachers to possess special abilities and knowledge, such as, for example, knowledge of what to teach, how to teach it, when to teach it as well as where the topic should be taught and why it should be taught (Attard, 2011).

The process of teaching encompasses a myriad of elements such as success criteria, content methodology, assessment (marking and reporting), a teacher's personality and his or her students' quality (Ayua, 2017). The activities and procedures that combine to define teaching all basically aim at providing learners with knowledge, skills and understanding at all levels of education (Ayua, 2017). Yet, however, teaching ultimately goes beyond mere communication of knowledge and skills to encompass such other ultimate processes and ends as participating with students in sharing knowledge, making sense of knowledge, seeking clarity and being critical of what is taught or learnt and making judgements based on evidence and information available (Gess-Newsome et al., 2002). The role of the teacher in all these activities and processes is to act as the facilitator of knowledge and skills, helping learners understand and discover knowledge and acquire critical skills to help them grow in their learning. But for all these to be possible, teachers must possess both the knowledge of and ability to use student-centred methods to teach learners.

1.2.2 SMASSE

Malawian secondary school students had reported poor performance in science subjects compared to humanities and languages until the turn of the millennium (Mbano, 2003). The persistent trend of poor performance in science subjects was worrying to government given the significance science, technology and innovation were assuming in global development at the turn of the 21st century. As such, in 2007, the Government of Malawi introduced a special intervention designed to improve performance of secondary school students in science subjects called the Strengthening of Mathematics and Science Secondary Education (SMASSE). Government of Malawi implemented this project in partnership with the Japanese International Cooperation Agency (JICA). The project was first piloted in the four districts of the South East Education Division (SEED), namely, Mangochi, Machinga, Balaka and Zomba. Thereafter, the project became a program under the Directorate of Teacher Education and Development (DTED) in the Ministry of Education.

SMASSE targeted in-service Mathematics and Science teachers with periodic capacity training to improve their skills and knowledge for teaching science subjects. Usually, SMASSE in-service capacity trainings were designed to improve science teachers' content knowledge, assessment techniques and teaching skills to enable them handle topics which teachers themselves essentially singled out as difficult to handle. Since 2007, SMASSE has been holding these week-long capacity training sessions annually.

At the 2018 training session, science teachers chose biotechnology in Biology as the topic which they needed special capacity training to teach. The reasons for choosing biotechnology were that, firstly, the topic had just been introduced in the reviewed Biology curriculum and that, finally, the topic fell under genetics and evolution which teachers considered difficult. SMASSE used the session as an opportunity for teachers to share knowledge of the best ways to handle the topic (SMASSE, 2018).

1.2.3 Teacher Knowledge Bases

As earlier pointed out, the ability of a teacher to initiate high quality teaching is positively or negatively influenced by their level of knowledge and understanding of the subject or topic they are teaching. This is referred to as the knowledge base, which is defined as a set of skills that a teacher needs to know to teach effectively and efficiently (Fernandez, 2014, p. 80). Thus, teaching is likely to be effective and meaningful if a teacher's knowledge bases, such as knowledge of the curriculum, knowledge of students and knowledge and mastery of teaching methods, are high (Williams & Lockley, 2012). A teacher's acquisition of factual knowledge of concepts of the topic and their understanding of the structure and sequencing of concepts are critical in learning as they assist students to discover various approaches to learning the subject content (Mishra & Koehler, 2006). In fact, several studies have shown that Pedagogical Content Knowledge (PCK) of a teacher is the core knowledge base which influences the ability of a teacher to plan lessons that are accessible to their students (Shulman, 1986, Grossman, 1990, Magnusson et al,1999, Abell, 2008). These discoveries and recommendations agree with findings in the Malawian context that suggest that the primary influencing factor for poor performance of learners in science subjects is teachers' inadequate content knowledge and pedagogical skills (MoEST, 2015).

1.2.4 Biotechnology and its significance

The Government of Malawi incorporated Biotechnology into the Malawi secondary Biology curriculum at the 2013 secondary school curriculum review. This was following the growing importance of biotechnology in the technology sector worldwide and it potential to positively impact the industrial, medical, agriculture and environmental sectors.

Biotechnology is defined as any use of biological organisms or processes in industrial, medical, agricultural and environmental engineering (Hulse, 1985). It involves the use of technology to use, modify or upgrade the part or whole of a biological system for industrial and human welfare (Naz, 2015). The United States of America's Office of Technology Assessment defines biotechnology as any technique that uses living organisms (or parts of organisms) to make or modify products, to improve plants or animals, or to develop microorganisms for specific purposes (OTA, 1988). This definition of biotechnology remains the widely accepted definition by many academicians within the industry.

The history of biotechnology dates back to the 19th century. The 19th century during which scientific agriculture and fermentation began. In fact, the study of processes of fermentation in yeast and bacteria in the production of food and beverages such as bread, cheese, tofu, beer and wine began in the ancient times, but it was not until the 19th century that techno scientists began to isolate microorganisms involved in these processes and study them carefully (Hulse, 1985). Scientists in this period were aided by techniques in scientific biology to isolate pure strands of various yeast and fungi involved in food and beverage production processes and then standardise mass production of these products (Hulse, 1985). This development led in the end to the establishment of teaching institutions and to the creation of both state-funded and industry-sponsored laboratories (Naz, 2015).

The term biotechnology was coined by Karl Ereky (1878 – 1952) of Hungary in 1919. Ereky used the term to describe general processes, involved commonly in industrial farms, of converting raw materials into useful products with the assistance of living organisms (Bhatia, 2018). However, higher education institutions in developed countries incorporated biotechnology as a field of study in about 1979. On the other hand, Researchers began showing interest to include biotechnology in the secondary school curriculum from 1998, with Professor G Wells and his fellow researchers credited with efforts to include biotechnology in technology education (Hin et al., 2019). These scientists advocated for the inclusion of biotechnology in the secondary school curriculum based on the success of the cloning of Dolly in 1997 (the sheep using DNA from two adult sheep cells), the successful decoding of the genome of rice in 2002 and the successful completion of human genome decoding and the sequencing of human genes on all 46 chromosomes (Hin et al., 2019).

Biotechnology has become increasingly important to the world since the dawn of the millennium because of its potential to impact science, academics and overall development (Moreland, Jones & Cowie, 2006). The growing significance of biotechnology influenced many countries across the world to integrate its themes in their secondary school science curriculum (Hanegan & Bigler, 2009). In line with the increasing significance of biotechnology to development, Malawi, too, tipped biotechnology as an important area of science to be given serious consideration (National Planning Commission, 2021).

Since its incorporation in the Malawi secondary school science curriculum in 2013, and since its introduction as a specific topic of study in the revised biology curriculum in 2017, a number of writers of recommended Biology teaching and learning textbooks have proposed different definitions for the term biotechnology. Msasa (2017) defines biotechnology as the use of living organisms and their body systems to develop new and useful products that help to improve human life. Chimocha and Lungu (2017), on the other hand, define biotechnology as the use of biological discoveries using genetic engineering in industries, medicine and agriculture. Avis et al (2018) define biotechnology as the application of biological organisms, systems, or processes to manufacturing or service industries. A close examination of all these widely used definitions of biotechnology in Malawian secondary school biology curriculum brings to light the fact that biotechnology is part of applied biology and technology and involves the use of living organisms.

Biotechnology as a topic familiarises students with the use of living organisms and biological processes in the fields of medicine, technology, engineering and other biological products (Srutirupa & Mohalik, 2013). It encompasses genetic modification, which involves the transfer of genetic material from one living organism, such as animals, plants or microorganisms, to another (Barış & Kırbaşlar, 2015). In food production systems, knowledge of biotechnology, especially genetic technology, can enable the transfer of desirable characteristics of one living organism to another, hence influencing desirable traits such as disease resistance and tolerance to adverse weather conditions like drought and floods. This is critical to the global goal to increase food production by about 70% to meet the ever-increasing demand for food by 2050 (WFP, 2021). Seen in this light, biotechnology becomes of even greater importance to developing countries of the world who struggle to produce adequate amounts of food to meet the nutritional needs of their populations in the face of such realities as climate change and environmental degradation. In medicine, knowledge of biotechnology has enabled developed countries to invent pharmaceutical solutions to treat different diseases and infections of humans and animals.

There are three famous fields of biotechnology, namely, genetic engineering, tissue culture and cloning. Genetic engineering, also referred to as genetic modification or recombinant DNA, involves the direct technological manipulation of an organism's genome where genes (the molecular blueprints that define an organism's characteristics) are transferred from one organism to another (Naz, 2015). Genetic engineering makes it possible to introduce certain gene combinations into organisms, hence influencing development of novel features that are not found in nature or cannot be acquired naturally.

Cloning involves techniques used to produce a precise genetic duplicate of another cell, tissue or organism. Therefore, a clone is a copy of material that shares the same genetic composition as the original (Naz, 2015). There are three methods of cloning, namely, gene cloning, reproductive cloning and therapeutic cloning. Gene cloning results in the production of duplicate copies of genes or DNA segments while reproductive cloning produces duplicates of whole animals. Therapeutic cloning produces embryonic stem cells which scientists can use to replace damaged or unhealthy tissues with healthy ones.

Tissue culture is a biological technique by which tissue pieces are cultivated in artificial environments to maintain their viability and functionality (Naz, 2015). A cultured tissue may be composed of a population of cells or a whole or partial organ. The cells in a culture tissue can divide or even alter in shape, size and function. In some situations, they may show specialised behaviour (for instance, muscle cells can contract) or may engage in cellular interactions.

Despite its widely acknowledged significance, biotechnology has met with severe criticism from other circles of thinkers who point out issues in biotechnology which they believe conflict with moral issues in our society. For example, such issues in biotechnology as

Genetically Modified Organisms (GMOs) and the Human Gene Cloning have attracted serious moral questions from some people (Fonseca et al., 2012). Thus, it is of critical importance that teachers handling biotechnology be fully conversant with the moral and ethical issues associated with the subject in addition to the actual conceptual and theoretical content they are expected to teach (Fonseca et al., 2012).

1.2.5 Biotechnology in Malawi's revised secondary school curriculum

As revealed elsewhere in this background discussion, biotechnology is a recent discussion in the Malawi secondary school Biology curriculum. Biotechnology was first taught as a standalone topic in the biology curriculum during the 2018/2019 academic year. In the previous biology syllabus, themes and concepts of biotechnology were covered under different topics which learners learnt at different levels of their learning. For example, learners learnt some themes and concepts related to biotechnology under the topics micro-organisms and Genetics. Under micro-organisms, students learnt the types of micro-organisms and their uses in the production of alcoholic drinks and the baking of bread. Under genetics, students learnt concepts of biotechnology such as animal and crop breeding.

The purpose for including biotechnology as an independent topic of study in the curriculum is to equip students with knowledge of plant and animal breeding strategies, genetic engineering and various applications of biotechnology in medicine, agriculture and other industries. Under genetic engineering, students learn recombinant DNA technology used in various applications such as insulin production such as insulin production and genetically modified organisms. In addition to studying the concepts in biotechnology, the topic is also designed to familiarise learners with moral and ethical issues in biotechnology as well as the misconceptions people have about biotechnology (MoEST, 2013).

5.3 1.3 Motivation of the study

The researcher chose to do a study on biotechnology and pedagogy because of the passion the researcher shares in biotechnology both as a theme and a topic of study, and also because of the growing significance of biotechnology to livelihoods (Kidman, 2009). Also, like many biology teachers in Malawian secondary schools, the researcher developed interest in how one can effectively teach biotechnology to secondary school learners as biotechnology is a recently introduced topic. It is worth acknowledging that the majority of biology teachers struggle to teach concepts, applications and issues in biotechnology because they themselves did not learn about the topic during their secondary school or professional training days.

The researcher also wanted to raise awareness of biotechnology to help address misconceptions people commonly have about biotechnology. In so doing, the researcher sought to help people appreciate the critical importance of biotechnology to the future of livelihoods and development in Malawi. Malawi, with its rapidly growing population, continues to struggle to achieve food security and to provide health services to its people. Applications of biotechnology can greatly improve food production systems and enhance access to quality medicine thus improving the quality of life. Students with good knowledge base of biotechnology can become key participants in the development of improved crop and animal varieties thus improving food security and nutrition.

On the other hand, the researcher hoped to use the study to motivate other researchers to start conversations on other emerging issues that spark interest and debate but are as important as biotechnology. The researcher also hoped that the study can incite other researchers to delve into further studies on biotechnology and pedagogy, such as investigating the best knowledge bases teachers of biology need to have to effectively teach concepts and applications of biotechnology as well as how they can help learners maintain an objective attitude towards biotechnology.

5.4 1.4 Statement of the problem

The introduction of biotechnology education in Malawi's secondary school curriculum is a relatively recent development. Concepts in biotechnology were first included in the curriculum in 2013, and biotechnology as a specific topic appeared in the 2017 revised biology syllabus. The decision to incorporate biotechnology into the school curriculum was influenced by its potential to greatly impact industry and agriculture. In contrast, most developed countries integrated biotechnology education into their secondary school curricula in the late 1990s (Kidman, 2009).

A study by Gul and Sozbilir (2015) revealed that most research in biology education focuses on teaching, learning, and student attitudes towards frequently studied topics such as ecology, genetics, and animal form and function. Similarly, research on biotechnology education has largely concentrated on studying attitudes and interests towards biotechnology (Fernandez, 2014). In Malawi, there is a notable absence of studies focusing on biotechnology as a theme in secondary school biology and its pedagogy. There are no studies on learner attitudes or responses to biotechnology, the experiences of biology teachers with the subject, or the approaches teachers use to teach this new topic. This is despite the acknowledged challenges secondary school teachers face in teaching biotechnology concepts and applications due to the rapidly evolving nature of information in the field (Naz, 2015; Kidman, 2009).

Given the many challenges that secondary school teachers encounter when teaching biotechnology and the potential impact that well-taught biotechnology knowledge can have on Malawi's science, technology development, and industrialisation efforts, this research aims to investigate the knowledge bases of secondary school biology teachers that affect their teaching of biotechnology concepts and applications to learners.

The fact that knowledge of content appears as a knowledge base in apparently all teacher knowledge base models, experts have developed clearly underlines the critical importance of content mastery to the potential of every teacher to handle subjects with ease and effectiveness. In fact, content mastery remains the key for every teacher to keep abreast with emerging issues and trends in science as knowledge continues to evolve rapidly and swiftly in the fields of science and technology and as new knowledge and discoveries continue to be incorporated in the curriculum. biotechnology has many abstract concepts which teachers find difficult to teach. It is for these reasons that the thesis examines how biology teachers' content knowledge and other knowledge bases, such as pedagogical content knowledge and knowledge of the curriculum, affect their teaching of biotechnology, which is a new topic in the curriculum under the core element of genetics and evolution.

5.5 1.5 Purpose of the study

The purpose of this study was to investigate secondary school biology teachers' knowledge bases that affect their teaching of concepts and applications of biotechnology.

1.5.1 Main research question

The main research question of the study was, "How do secondary school biology teachers use their knowledge bases in teaching Biotechnology concepts?"

1.5.2 Specific research questions

To answer the main research question, the study developed and was guided by the following specific questions:

1. How much content knowledge of the biotechnology topic do biology teachers have?
2. What topic-specific teaching strategies do biology teachers use in teaching biotechnology concepts?
3. What knowledge of students' conceptions and learning difficulties do biology teachers have about biotechnology?
4. How do biology teachers assess students' knowledge and understanding of biotechnology concepts?
5. How do biology teachers use the biotechnology curriculum knowledge when planning and implementing the biotechnology lessons?

5.6 1.6 Significance of the study

This study provides an in-depth analysis of biology teachers' knowledge bases for teaching a biotechnology topic. It offers valuable insights for teacher educators on how biology teachers utilise their knowledge in lesson preparation, classroom instruction, and post-teaching evaluations. By drawing from diverse sources such as content representation, interviews, classroom observations, document analysis, and tests, the study identifies the specific knowledge bases essential for teaching biotechnology.

Furthermore, this research highlights the challenges teachers encounter in the classroom. Understanding teachers' content knowledge alone is insufficient to gauge their effectiveness; therefore, it is crucial to explore their content knowledge, pedagogical content knowledge, and other knowledge bases, areas that have not been fully investigated which could assist the pre-service educators on how to train pre-service teachers the teaching strategies of the different abstract concepts of biotechnology. The curriculum developers should ensure that they textbooks have the relevant illustrations to aid in explaining the concept processes and abstract concepts.

This study contributes meaningfully to the literature by being one of the first comprehensive examinations of Malawian teachers' knowledge bases. It provides a critical analysis of the Malawian context where biotechnology is newly introduced in the biology MSCE curriculum. The findings also lay the groundwork for future research into teachers' knowledge bases in other new biology topics or subjects at the primary, secondary, and tertiary levels which might be introduced as science is evolving rapidly.

5.7 1.7 Definition of terms

Knowledge base: According to Guerriero, (2012) Teachers' 'knowledge base' encompasses all of the cognitive skills needed to create effective teaching and learning settings. This expertise, according to research, can be researched. However, determining the substance of this knowledge base is a difficult task. The first major study on teacher knowledge (Shulman, 1987) divided teacher knowledge into seven categories as listed and defined below: -

Pedagogical content knowledge (PCK): Shulman established the concept of PCK as part of what he considered a knowledge base for teaching (Fernandez (2014). In his list of seven (7) knowledge bases that might form the minimum for instructors, Shulman (1987a) conceptualised it as a combination of content and pedagogy. He found pedagogical content knowledge to be particularly interesting since it combines content and pedagogy into an awareness of how specific topics or concerns are organised, represented, and suited to the various interests and skills of learners, and presented for instruction. Several academics have reconstructed the concept by laying out and distinguishing the various components (Turner-Bisset, 1999). PCK is the knowledge base once thought to be the most important aspect of a teacher's expertise, and it has since been extensively researched.

Pedagogical knowledge: This is the knowledge that has cross-curricular principles and strategies for classroom management and organisation.

Content knowledge: This is the knowledge of facts and concepts and understanding of the structure of a subject.

Knowledge of students: This is knowledge in which teachers are required to have a very good understanding of their students' learning difficulties in every topic they teach.

Curriculum knowledge: This is the knowledge that includes the sequence of topics or concepts to be taught and materials and resources suitable for a particular topic or subject.

Knowledge of educational ends, purposes and values and their philosophical and historical grounds: This includes a clear philosophical understanding of a specific subject and being able to explain how and why the different concepts within are linked to make students understand the subject.

Knowledge of educational context: This is knowledge teachers must have. This includes the workings of a group or classroom, the governance, financing of the school, school and communities' culture if the teachers are to work properly in the schools.

5.8 1.8 Organisation of the thesis

This research study is organised into five chapters as follows:

Chapter one sets the stage by providing the background of the study. It covers the student-centred curriculum, SMASSE and teacher knowledge bases, the significance of biotechnology, and its introduction into the secondary school curriculum. Additionally, this chapter includes the motivation for the research, a problem statement, specific research questions, the significance of the study, and definitions of key terms. It concludes with a summary outlining the organisation of the chapters in the dissertation.

Chapter two delves into the discussion of knowledge bases, summarizing various models and presenting the theoretical framework for the study, referred to as the consensus model. It also reviews studies that describe knowledge bases for teaching biology, strategies for teaching biotechnology, and knowledge bases specifically for teaching biotechnology. Furthermore, it discusses studies that have employed the consensus model and concludes with a summary of the chapter.

Chapter three outlines the qualitative approaches utilised in the study. It details the research methodology, study design, data generation strategies, and data analysis methods. Additionally, it addresses the trustworthiness of the design, including the validity and reliability of the study, and covers ethical considerations and limitations.

Chapter four presents the results and discussion of the findings. It is divided into two main sections. Section 4.1 provides the study's findings, while Section 4.2 offers a discussion of these findings. The chapter also includes three case profiles, one for each participant. The first section aims to provide evidence for the assertions made in the subsequent section, which offers a cross-case analysis and discussion of the emergent assertions from the data.

The final chapter, chapter five, concludes the study with a summary of the findings and a discussion addressing the research questions. It also explores the implications for practice and provides recommendations for future research.

5.9 1.9 Summary of the chapter

This chapter has given a background of the study, highlighting the background and context of the study and problem which the study sought to address. The chapter has also described the motivation and purpose of the study, stating the main question of research and the supporting questions of the study. In continuing with the statement of the problem and research questions, the chapter has justified the relevance of the study to different levels of groups of interest. To ensure clarity and focus throughout the study, the chapter has also defined different technical terms used throughout the study. In the final analysis, and for the purposes of maintaining focus and direction, the chapter has described the structure and organisation of the whole thesis.

CHAPTER TWO

REVIEW OF RELATED LITERATURE AND RESEARCH

5.10 2.1 Chapter overview

This chapter reviews the literature and research that relate to the aim, orientation and context of this study. It highlights and discusses conceptual, theoretical and empirical studies that have previously been conducted on knowledge bases in relation to science pedagogy, with particular attention to biotechnology. The chapter discusses the literature in a way that situates the present study within certain theoretical and conceptual framework and in a way that brings out clearly the gap which the current study sought to address. Thus, in respect of this, the chapter discusses the theoretical framework within which the current study was situated, the knowledge bases for teachers, the models of pedagogical content knowledge, and findings of empirical studies on these aspects.

5.11 2.2 Knowledge bases

This section discusses various models of pedagogical content knowledge and the knowledge bases in education generally and in science education specifically. The section also discusses the theoretical framework used for this study.

The popular view held by the majority of people is that knowledge of content of a particular subject is all that a teacher needs to effectively teach the subject (Attard, 2011). However, although content mastery of a subject remains of critical significance to a teacher's ability to teach a subject effectively, it is nevertheless not the only knowledge base a teacher needs to handle a subject with effectiveness (Fernandez, 2014). In fact, as is the popular view of many thinkers in the field of pedagogy, a teacher needs to combine a variety of knowledge bases and skills to truly qualify as an effective teacher (Attard, 2011).

Shulman (1986) identified seven knowledge bases a teacher needs to have to qualify as effective teacher. These are content knowledge, general pedagogical knowledge, curriculum knowledge, pedagogical content knowledge, knowledge of learners and their characteristics, knowledge of educational contexts and knowledge of educational ends, purposes and values (refer to figure 2.1 for an illustration of the knowledge bases). The knowledge bases Shulman proposes, such as, for example, content knowledge, pedagogical content knowledge and curriculum knowledge, are closely interconnected, and this close interconnection makes the task of differentiating them difficult (Maniraho, 2017).

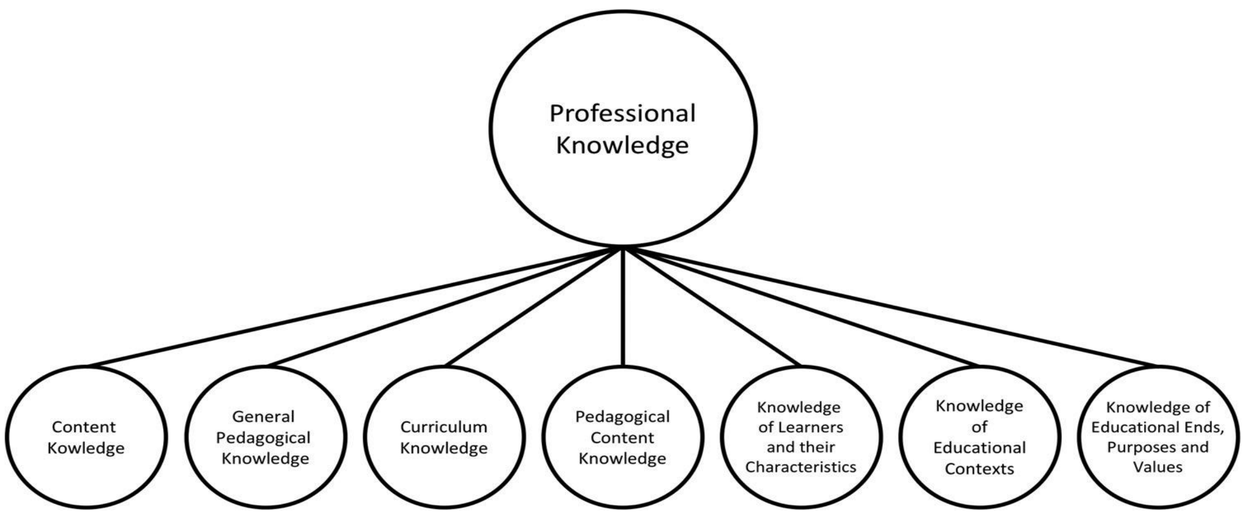


Figure 2.1: Teacher professional Knowledge according to Shulman, 1987 (Adopted from Neumann et al, 2018, pp 4)

Content knowledge describes the knowledge, understanding, skills and dispositions which a teacher needs to communicate to a learner (Shulman, 1986). It includes knowledge of concepts, theories, ideas, proofs, practices and approaches which are key to a specific subject (Shulman, 1987). Of all these, content knowledge is tipped to be of utmost significance to the ability of a teacher to deliver high quality lessons (Barış & Kırbaşlar, (2015). Thus, the ability of the teacher to handle concepts in science and to plan relevant assessments is positively or negatively affected by their level of mastery of the content of the subject (Kind, 2014).

A study on content knowledge was first conducted in USA by Rolya and Rolya on primary school science teachers in the 1930s. The study found that teachers lacked both adequate and accurate knowledge of a number of topics covered in the science curriculum (Kind, 2014). Another study conducted by Ameh and Gonston (1985) on science teachers' content knowledge also found that many science teachers misconceived certain life and physical science concepts. The study further noticed that these misconceptions were uniform among the teachers that were studied regardless of differences in the teachers' nationality.

More studies about content knowledge have been carried out in the Physics subject than in the subjects of Biology and Chemistry simply because Physics covers concepts which are more abstract than Biology and Chemistry (Kind, 2014).

General pedagogical knowledge, the second knowledge base Shulman describes, encompasses broad principles and strategies of classroom management and organisation that appear to transcend subject matter. This knowledge base also includes a teacher's awareness of the educational purposes, the methods and strategies of teaching and learning, knowledge of the techniques or methods used in the classroom, the nature of the target audience, and the strategies for assessing students' knowledge.

Curriculum knowledge, the third knowledge base, concerns what Shulman describes as the "tools of the trade". It encompasses a teacher's knowledge of the sequence of topics or concepts to teach and the resources and materials needed to teach a given topic. Ball, Thames and Phelps (2008) also described curriculum knowledge as what is represented by the full range of programs designed for the teaching of particular subjects and topics at a given level, the variety of instructional materials available about those programs, and the set of characteristics that serve as both the indications and contraindications for the use of particular curriculum or program materials in particular circumstances.

Curriculum knowledge is classified into lateral curriculum knowledge and vertical curriculum knowledge. Lateral curriculum knowledge describes the ability of the teacher to relate content to topics being taught to learners in different classes at the same time. Vertical curriculum knowledge refers to the knowledge students have acquired in the previous years of their learning of the content of the subject versus what they are expected to learn in future in the same subject (Shulman, 1986).

Shulman's fourth knowledge base is knowledge of learners and their characteristics. Awareness of learners' diversity is important as it enables teachers to diversify their instructional methods and approaches to accommodate the varying individual needs and abilities of learners (Sadler et al., 2013). Also, teachers who have greater awareness of their learners, including the learning difficulties of the learners, are better placed to plan and deliver lessons that incorporate relevant illustrations, representations and activities that assist the learners to get the best out of the topic (Van Driel, Berry & Meirink, 2014).

In addition to knowledge of learners and their characteristics, Shulman also identifies knowledge of educational contexts as the other knowledge base which teachers need in order to be effective in their teaching. This knowledge covers awareness of the workings of the group or the classroom, arrangements for governing and financing schools at district or division levels as well as the character of communities and cultures. Teachers must be conversant with the type of school they are teaching at as well as the culture of the communities from which their learners come from or their school is situated in as these profoundly influence how learning takes place in the classroom.

A teacher's knowledge of educational ends, purposes and values is another knowledge base Shulman identifies. Shulman's view in as far as this knowledge base is concerned is that a teacher's ability to handle specific subjects is enhanced when they have broader awareness of the philosophical and historical grounds that save as rationale for including the subject in the curriculum and when they are able to give vivid description of the links between different concepts within the subject to help students understand the subject better.

The last knowledge base Shulman identifies is pedagogical content knowledge (PCK) which he acknowledged as being of special interest since it identifies the distinctive bodies of knowledge for teaching. Shulman defined pedagogical content knowledge as an understanding of the most useful ways of representing concepts within a topic. These representations may include illustrations, explanations and demonstrations that are used to convey core concepts of the topic to make them easily understandable to learners. Pedagogical content knowledge also includes an understanding of what makes a specific topic easy or difficult to understand. It also encompasses the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of most frequently taught topics and lessons of a subject (Shulman, 1989).

Shulman elaborately treated representations such as analogies, similes, examples and metaphors in his discussion of pedagogical content knowledge, but he did not give detailed explanation of activities and knowledge of content and students within the context of PCK. Also, Shulman did not discuss teaching materials and organisation of content as he was discussing knowledge of the curriculum in specific subject areas.

Building on Shulman and Syke's seven knowledge bases, Tamir (1988) proposed a teacher knowledge framework composed of six main categories. These categories included general liberal education, personal performance, subject matter, general pedagogy, subject matter specific pedagogical knowledge, and fundamentals of the teaching profession. Tamir included 'skill' as a feature in his framework and underscored the difference between knowledge and skill as they relate to pedagogy.

Tamir used personal performance to refer to how a teacher looks, speaks, listens and moves about in the classroom. Tamir's subject matter is the alternative term for Shulman's content knowledge. He split subject matter into knowledge, such as major ideas and theories of particular discipline, and skills, such as how to use a microscope. Tamir also identified two substantive components of subject matter, namely, content knowledge and syntactic knowledge.

Tamir proposed four subcategories of general pedagogical knowledge, namely, student, curriculum, instruction and evaluation (refer to figure 2.2). He then identified skills and knowledge for each of the four subcategories. Tamir identified Piaget's development levels and skills which specifically described how to deal with hyperactive students under the subcategory of student. Under the subcategory of curriculum, Tamir focused on knowledge which described the nature, structure and rationale of Blooms Taxonomy and the skills a teacher needs to prepare a learning unit. Under instruction as the third subcategory, which also called teaching and management, addresses different ways of assigning turns to students in class discussions. It also focuses on skills for formulating high level questions. The last subcategory, evaluation, describes different types of tests and outlines skills for designing a test such as formulating items in a multiple-choice test.

Tamir uses similar subcategories of general pedagogical knowledge for specific pedagogical knowledge to indicate different emphases. In the first subcategory, called student, Tamir describes students’ knowledge that define specific common conceptions and misconceptions on a given topic and the skills that describe how to diagnose a student’s conceptual difficulty on a given topic. In the second subcategory, curriculum, Tamir defined knowledge as the pre-requisite concepts needed for understanding a given topic such as biotechnology as well as the skills a teacher needs to design an inquiry-oriented laboratory lesson.

In the third subcategory, instruction (teaching and management) Tamir describes the knowledge a learner needs in a laboratory lesson as it consists of three phases. These are pre-lab discussion, performance and post-laboratory discussion. Apart from this knowledge, teachers must have skills on how to teach students about different apparatus such as how to use a microscope.

The final subcategory is evaluation, which is the knowledge of the nature and composition of the practical tests, assessment inventory and skills on how to assess manipulation laboratory skills.

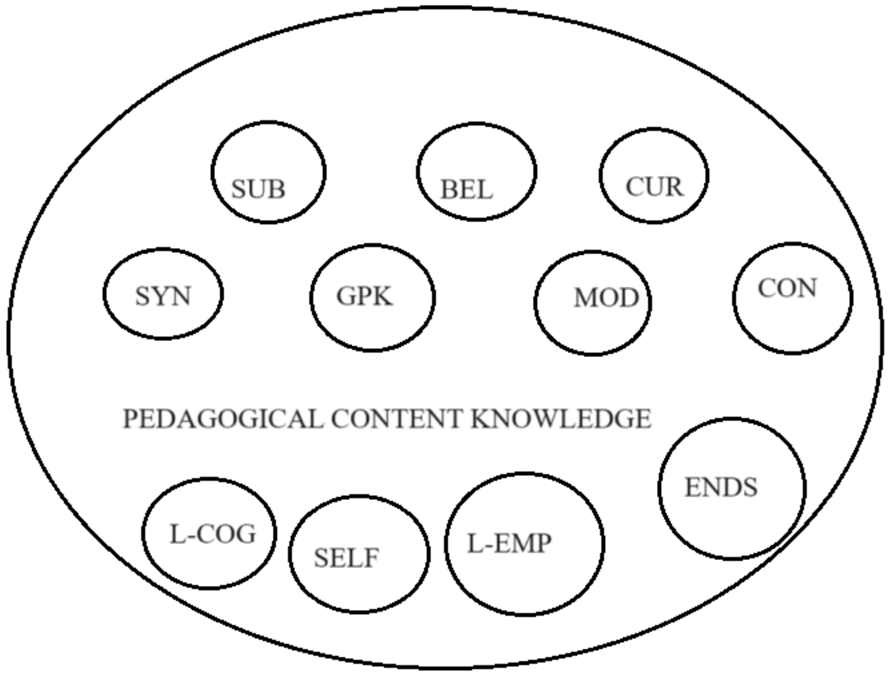
1 **GENERAL LIBERAL EDUCATION**
2 **PERSONAL PERFORMANCE** How do I look, speak, listen, move in class?
3 **SUBJECT MATTER**
3.1 **Knowledge**: Major ideas and theories of a particular discipline
3.2 **Skills**: How to use a microscope
4 **GENERAL PEDAGOGICAL**
4.1 Student
4.1.a **Knowledge** : Piaget's development levels
4.2.b **Skills** : How to deal with hyperactive students
4.2 Curriculum
4.2.a **Knowledge**: The nature, Structure, and rationale of Bloom's Taxonomy
4.2.b **Skills** : How to prepare a learning unit
4.3 Instruction (Teaching and Management
4.3.a **Knowledge** : Different ways of assigning turns to students in class discussion
4.3.b **Skills** : How to formulate a high level question
4.4 Evaluation
4.4.a **Knowledge** : Different types of tests
4.4.b **Skills** :How to design a multiple choice item
5 **SUBJECT MATTER SPECIFIC PEDAGOGICAL**
5.1 Student
5.1.a **Knowledge** : Specific common conceptions and misconceptions in a given topic
5.1.b **Skills** : How to diagnose a student conceptual difficulty in a given topic
5.2 Curriculum
5.2.a **Knowledge** : The pre-requisite concepts needed for understanding photosynthesis
5.2.b **Skills** : How to desing an inquiry oriented laboratory lesson
5.3 Instruction (Teaching and Management)
5.3.a **Knowledge** : A laboratory lesson consists of three phases: pre-lab discussion, performance and post-laboratory discussion
5.3.b **Skills** : How to teach students to use a microscope
5.4 Evaluation
5.4.a **Knowledge** : The nature and composition of the practical Tests assessment Inventory
5.4.b **Skills** : How to evaluate manipulation laboratory skills
6 **FOUNDATIONS OF THE TEACHING PROFESSION**

Figure 2.2: A framework for teachers' knowledge (Tamir (1988, page 100)

Another scholar who studied knowledge bases teachers need to have to succeed in their teaching is Turner-Bisset. Turner-Bisset (1999) added knowledge of self as another important knowledge base a teacher needs in their profession in addition to the knowledge bases Shulman described.

Knowledge of self refers to an understanding of oneself or one's motives or character (Oxford Dictionary). Knowledge of the self is tipped to be one of the most important bases every teacher must strive to acquire as teaching is a profession that required substantial investment of the self and in which the self plays a critical role in evaluation and reflection. Knowledge of the self is vital in helping teachers to understand the nature of their employment and to reflect on their practice (Gess-Newsome et al., 2017). As Turner-Bisset (1999) posits, it is easier for a person to understand the perception a teacher attaches to their work and the depth of their connection with it by observing the value the teacher attaches to personal identity.

The second of Turner-Bisset's knowledge base is subject content matter. Like Shulman, Turner-Bisset also split subject content matter into substantive subject knowledge, syntactic subject knowledge and beliefs about the subject. She claimed that substantive subject knowledge consists of facts and concepts of a discipline. She defined syntactic knowledge as the ability to understand the words and phrases within a sentence of a particular subject or content. For her, syntactical knowledge provides the ways and means through which propositional knowledge is created and established. As for knowledge of learners, she split it into cognitive knowledge and empirical or social knowledge (see figure 2.3). Unlike Shulman (1987), Turner-Bisset identified all the knowledge bases she described as components of Pedagogical Content Knowledge (PCK).



KEY TO CODES

SUB - Substantive Knowledge

SYN - Syntactic Knowledge

BEL - Beliefs about the Subject

CUR - Curriculum Knowledge

CON - Knowledge of Contexts

SELF- Knowledge of Self

MOD - Knowledge/Models of Teaching

L-COG - Knowledge of Learners: Cognitive

L-EMP - Knowledge of Learners: Empirical

ENDS - Knowledge of Educational Ends

Figure 2.3: Knowledge bases for teaching: the model (Source: Turner-Bisset, 1999, page 47)

Grossman (1990) also developed a systematic representation of Shulman's knowledge bases by proposing four interacting components that form the knowledge base for teaching. He identified general pedagogical knowledge, subject matter knowledge, pedagogical content knowledge and knowledge of context (refer to figure 2.4).

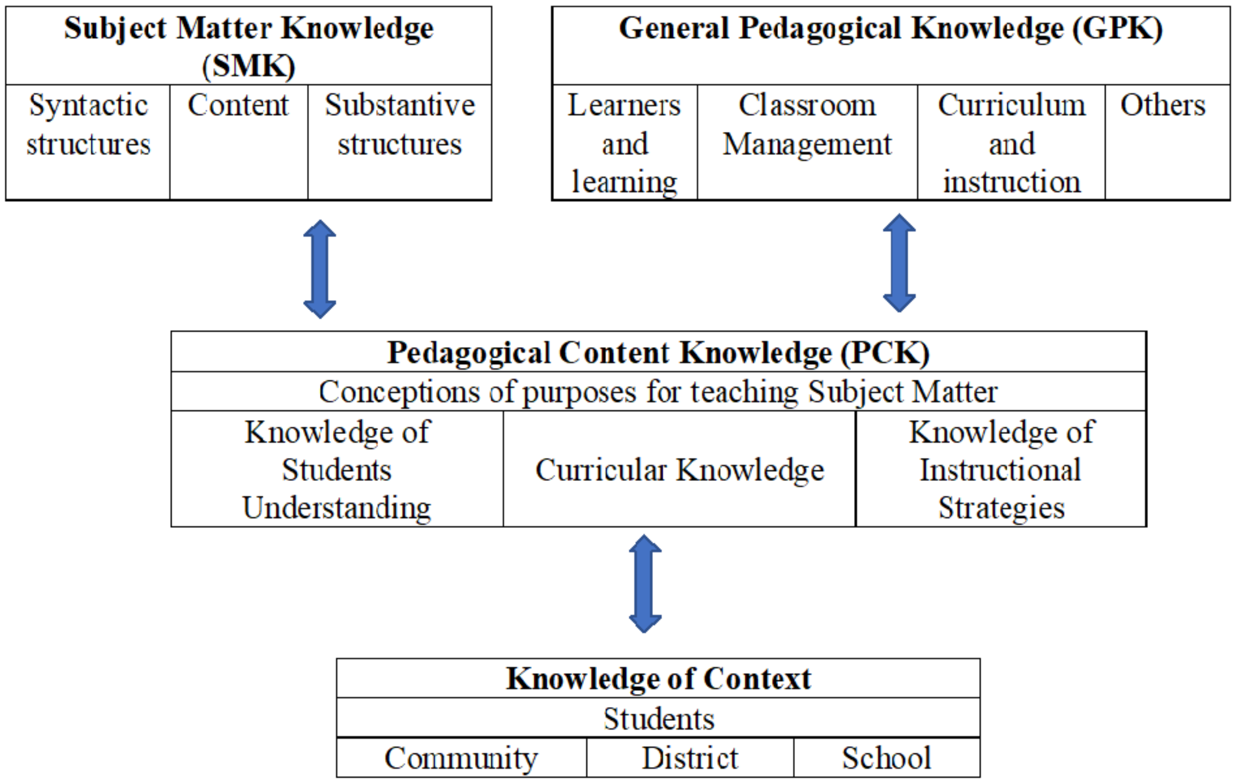


Figure 2.4: Model of Teacher Knowledge (From Grossman, 1990, p5)

As can be seen in figure 2.4, pedagogical content knowledge assumes a central position in Grossman's knowledge base framework as, according to Grossman, it is the knowledge base that interacts with the rest of the knowledge bases. Grossman describes pedagogical content knowledge as the pedagogical knowledge that is both context-specific and content-specific. Grossman identifies three components of knowledge that make up pedagogical content knowledge, that is, knowledge of students' understanding, knowledge of the curriculum and knowledge of instructional strategies. His view is that these components are all influenced by a teacher's understanding of the purposes for teaching subject matter.

Grossman identifies three components for subject matter knowledge, namely, syntactic structures, content and substantive structures. He also identifies three components for general pedagogical knowledge which are learners and learning, classroom management, and curriculum and instruction. But, as earlier indicated, Grossman sees that both subject matter knowledge and general pedagogical knowledge are influenced by pedagogical content knowledge. Pedagogical content knowledge, in turn, is influenced by knowledge of context whose focus is on students as they relate to the school, community and the district.

It is, thus, imperative that teachers receive adequate training and orientation in these knowledge bases so they can employ the knowledge and skills gained from them to plan, prepare and deliver lessons students can easily understand.

Carlsen (1999) is another scholar to have proposed a model of the knowledge bases teacher need to teach effectively. Carlsen's model, which he called domains of teacher knowledge, specifically targeted science teachers. The model described five main knowledge bases for teachers, namely, general pedagogical knowledge, subject matter knowledge, pedagogical content knowledge, knowledge about specific context and knowledge about the general education context (refer to figure 2.5 for the model).

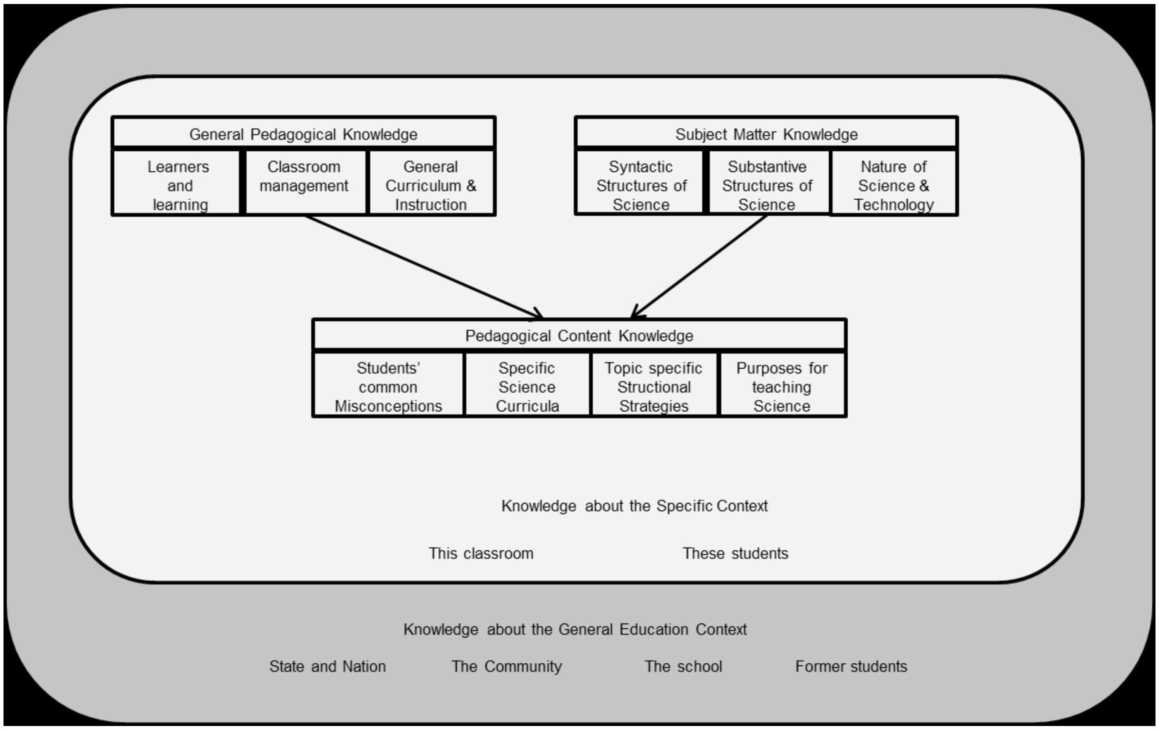


Figure 2.5: Domains of a teacher (Source: Carlsen, 1999, p.136)

The components of Carlsen's general pedagogical knowledge included learners and learning, classroom management and general curriculum and instruction. In relation to the teaching of science subject, Carlsen identified syntactic structures of science, substantive structures of science and nature of science and technology as components of subject matter knowledge. Carlsen's pedagogical content knowledge, on the other hand, comprises students' common misconceptions, specific science curricula, specific instructional strategies and purposes for teaching science.

Carlsen added two more knowledge bases to his domain of knowledge. These are knowledge about the specific context and knowledge about the general educational context. Knowledge about the specific context focuses on the classroom where learning takes place while knowledge about the general educational context looks at the political, social, cultural and economic context, both at community and national level, in which the school is situated. Like Shulman (1986) and Grossman (1990), Carlsen believed contexts profoundly influence teaching and learning, whether positively or negatively.

A widely used and acknowledged knowledge base framework that was built from earlier models is one developed by Magnusson, Kraick and Borko (1999). Magnusson et al. (1999) proposed four knowledge bases in their model. These include pedagogical content knowledge, knowledge of context, subject matter knowledge, knowledge of pedagogy and knowledge and beliefs about context. The knowledge base called knowledge and beliefs about context was added because they believed that a teacher's beliefs potentially influence all facets of teaching almost the same way as their knowledge of the subject matter influence their teaching (see figure 2.6). In fact, as will be seen from figure 2.6 illustrating the knowledge bases, the model proposed by Magnusson et al (1999) shows that there is a reciprocal relationship between the knowledge bases and their components (that is, this is illustrated by the two direction arrows used in the framework).

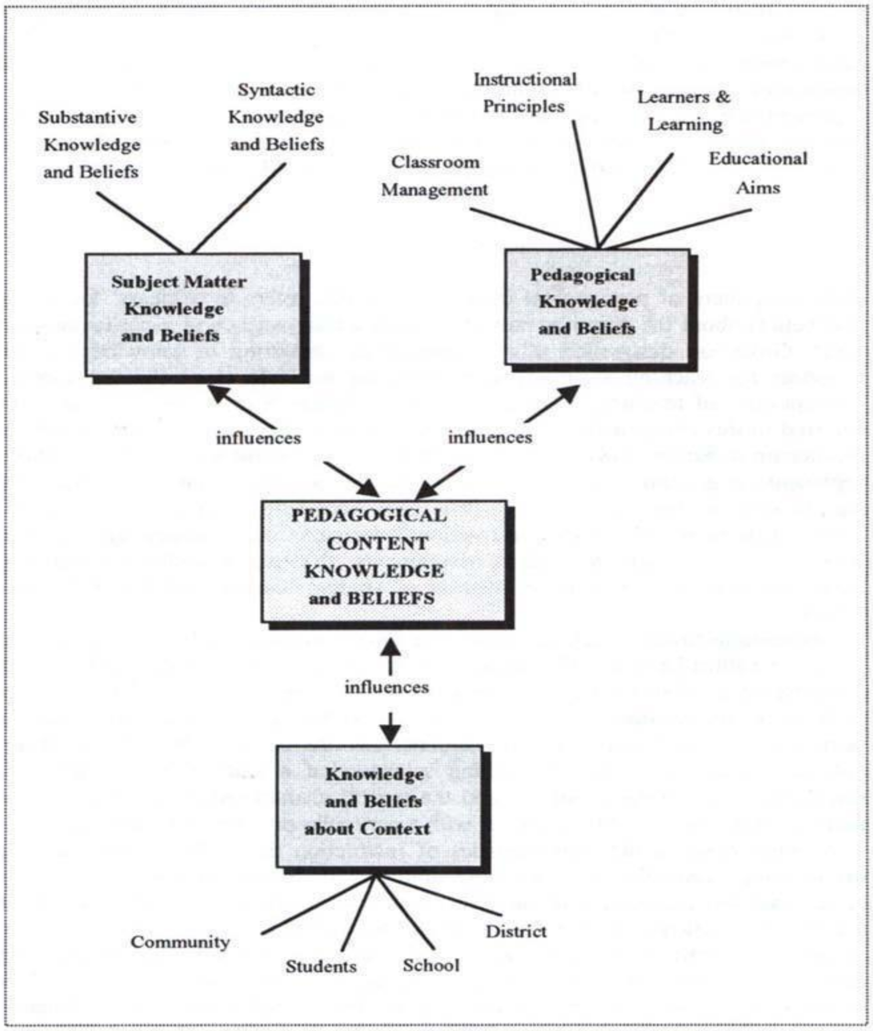


Figure 2.6: Magnusson et al. (1999, p.98) Model of the relationships among the domains of teacher knowledge.

Basing their model on the earlier work and conceptualisation done by Grossman (1990) and Tamir (1988), Magnusson et al (1999) proposed five components of pedagogical content knowledge critical for teaching science subjects (see figure 2.7). These included (1) orientation towards science teaching; (2) knowledge and beliefs about science curriculum; (3) knowledge and beliefs about students' understanding of specific science topics; (4) knowledge and beliefs about assessment in science; and (5) knowledge and beliefs about instructional strategies for teaching science.

According to Magnusson et al. (1999)'s model, orientations in the teaching of science are organised according to the emphasis of the instruction. The model also divided knowledge of the curriculum into knowledge of the goals and objectives of the knowledge of specific curricula program. The knowledge of goals and objectives consists of the knowledge teachers possess about learners' prior knowledge and prerequisite knowledge about the topic of discussion. It also encompasses the knowledge teachers have of the success criteria (objectives) of the topics they are to teach learners, and also awareness of guidelines for handling topics within an academic year (Magnusson et al., 1999).

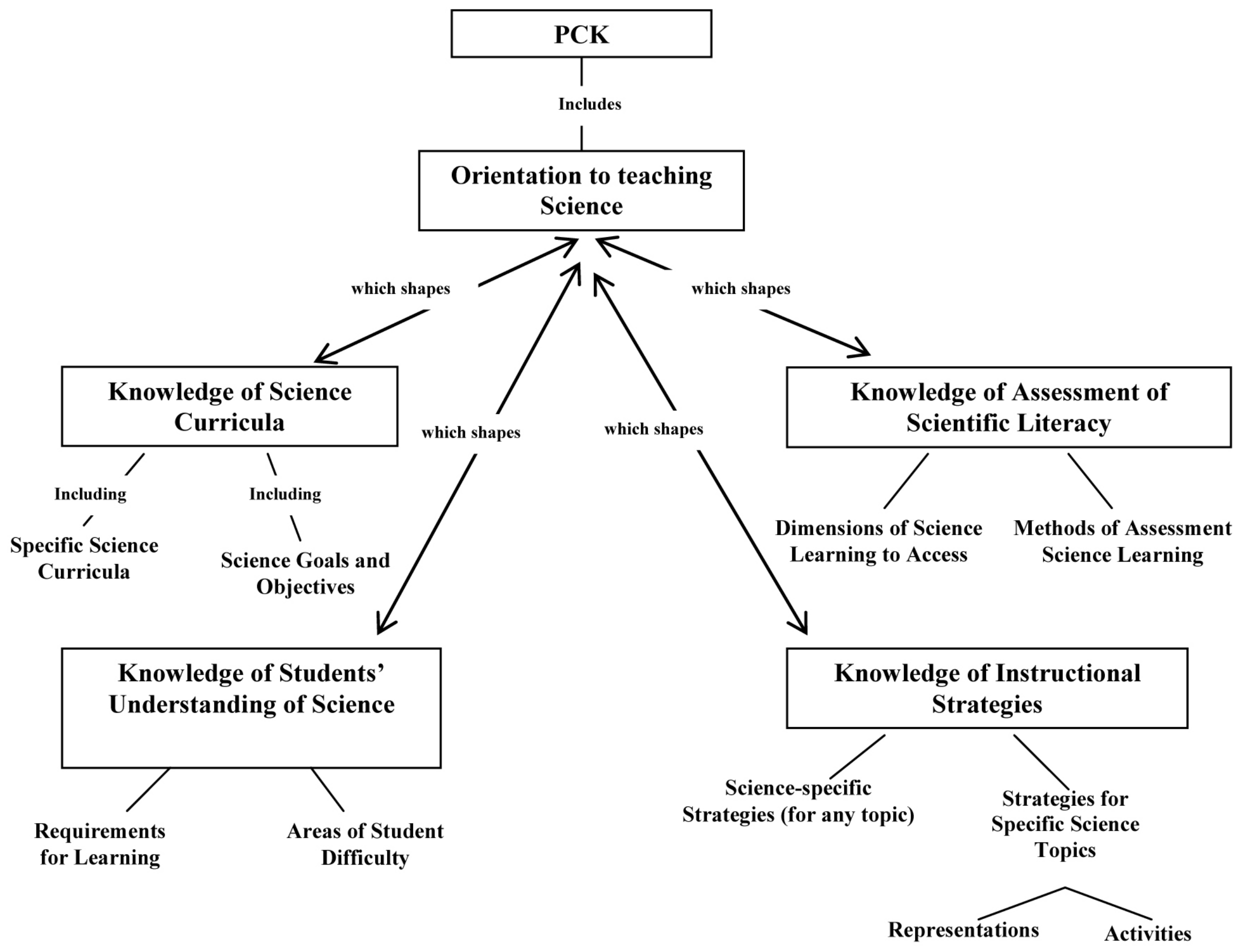


Figure 2.7: Components of Pedagogical Content Knowledge for science teaching (From Magnusson, Kraick, and Borko (1999, p 99).

Knowledge of specific curricular programs concerns a teacher's knowledge key and strategic resources, materials and activities essential in the teaching of specific areas of science as well as specific topics in science. In line with this, it is always imperative that a teacher be conversant with the science curriculum, especially with reference to the new topics that have been incorporated into the syllabus following periodical curriculum reviews and the core elements under which the new topics fall.

Magnusson et al. (1999) treated knowledge of students as a component of pedagogical content knowledge and not as a standalone knowledge base as Shulman treated it. The importance of a teacher's knowledge of students, according to Magnusson et al. (1999), is that it enables teachers to easily assist learners to acquire and master specific scientific knowledge.

Magnusson et al. (1999) also treated knowledge of assessment in science as a component of pedagogical content knowledge. Shulman (1986) did not specifically describe knowledge of assessment in science as either a knowledge base or a component of any of the knowledge bases because he was not specifically concerned with science education. However, knowledge of assessment as a base was proposed by Tamir (1988), although not specifically attached to science education. In Magnusson et al. (1999), knowledge of assessment is used to describe a teacher's knowledge of assessment principles, practices and methods, which enables them to engage different methods of assessment to develop valid and reliable assessments for learners.

The final component of pedagogical content knowledge which Magnusson et al. (1999) treats in their model of knowledge bases is knowledge of instructional strategies. This encompasses a teacher's knowledge and awareness of subject-specific strategies and topic-specific strategies. Subject-specific strategies are more general and apply to all science subject, and may include strategies for teaching biology or physics. Topic-specific strategies, on the other hand, are specially tailored skills for teaching specific themes and topics within a subject. They may include tailored skills and strategies for teaching biotechnology within biology or hydrocarbons within chemistry. The biology curriculum suggests general strategies which teachers can use to teach each topic, and these strategies vary depending on the nature and demands of the topic (MoEST, 2013).

The model of Magnusson et al. (1999) also adds orientation to teaching science and knowledge of assessment of scientific literacy as components of pedagogical content knowledge.

Despite being widely acclaimed as an improved version, Magnusson et al’s model, however, did not discuss topic specific PCK as it described science in general. Their model also did not discuss learners’ conception of learning the subject matter, which Shulman (1986, 1987), Tamir (1988) and Grossman (1990) discussed as a component of pedagogical content knowledge. On the other hand, both Magnusson et al and Carlsen’s models were intrinsically concerned with addressing knowledge bases in science education and their components. But Carlsen’s knowledge base model proved that general pedagogical knowledge and subject matter knowledge influence pedagogical content knowledge, while pedagogical content knowledge does not influence general pedagogical knowledge and subject matter knowledge. On the contrary, Magnusson et al.’s knowledge base model showed that the knowledge bases and components of pedagogical content knowledge bases and their components influence each other in a kind of a reciprocal way.

Park and Oliver (2008a) carried out a study to understand the factors that influence a teacher's pedagogical content knowledge. Their study investigated ways in which the process used by the National Board Certification (NBC) influences teachers' pedagogical content knowledge. Using qualitative data generated from in-depth interviews with experienced biology teachers, Park and Oliver established that the National Board Certification process really did affect teachers' instructional aspects, such as (a) reflection on teaching practices and students' learning, (b) implementation of inquiry-based instruction, (c) assessment of students' learning, (d) understanding of potential students' learning difficulties and (e) implementation of new and innovative methods.

Park and Oliver (2008b) carried out another study in 2008 to further examine pedagogical content knowledge in the context of teaching and learning. Using a case study design based on a constructivist framework, Park and Oliver conducted semi-structured interviews, lesson observations and document analysis to discover further details about pedagogical content knowledge. The findings of their study were in many respects similar to those of the preceding study they conducted, but they discovered a new aspect of pedagogical content knowledge which is teacher efficacy. Park and Oliver also deduced two models of pedagogical content knowledge from the findings of their study, and they called these new models the Hexagonal Model of PCK and the Pentagonal Model of PCK (see figures 2.8 and 2.9).

Park and Oliver's Hexagonal and Pentagonal Models respectively included teacher efficacy as an aspect of pedagogical content knowledge. They used teacher efficacy to describe the ability of a teacher to teach effectively using effective methods for a specific objective and for a specific activity.

Park and Oliver's Hexagonal and Pentagonal Models had five teacher knowledge bases as components of PCK, which is also the same number of knowledge bases Magnusson et al.'s Model had. However, Park and Oliver's Hexagonal and Pentagonal Models differ from Magnusson et al.'s model in that Park and Oliver's models imply that the knowledge bases influence each other in reciprocal way, thus making them interconnected. This is unlike Magnusson et al.'s model in which the knowledge bases do not portray a reciprocal relationship. Another fundamental difference between Park and Oliver's models and the Magnusson et al.'s model is that all knowledge bases in the Magnusson et al.'s model are related to the knowledge of orientation to the teaching of science and never outside the orientation of science whereas Park and Oliver's models show that a teacher might develop PCK through the integration of "Reflection-on-action" and "Reflection-in-action".

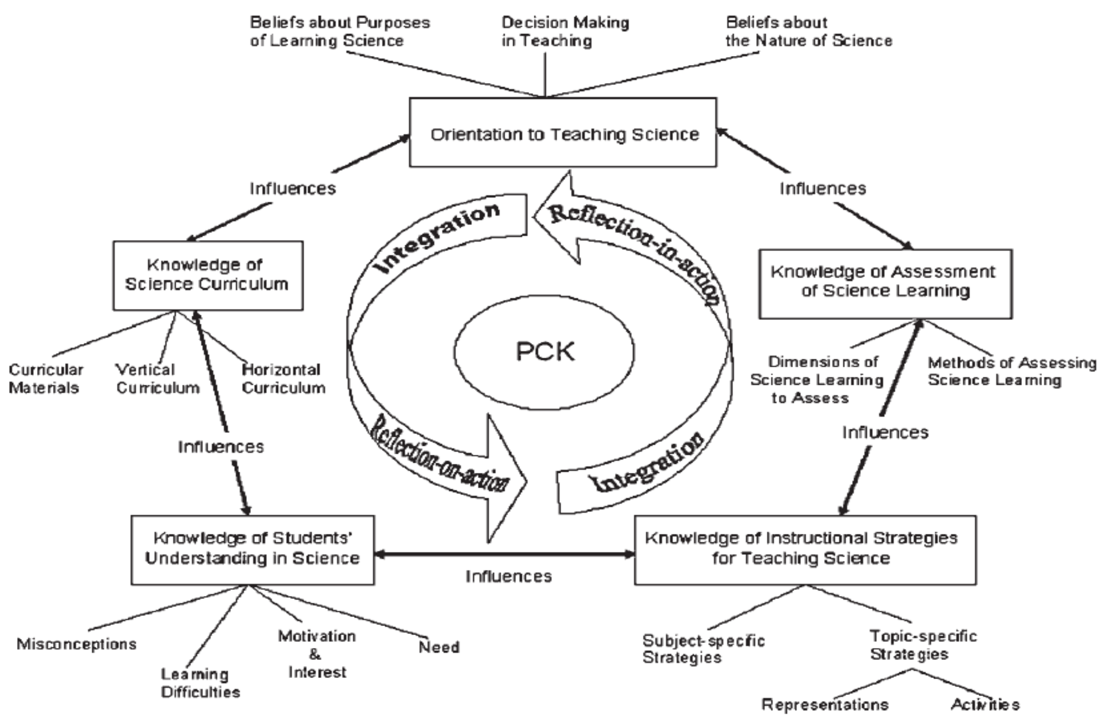


Figure 2.8: Pentagonal model of PCK for science teaching (Park and Oliver (2008a).

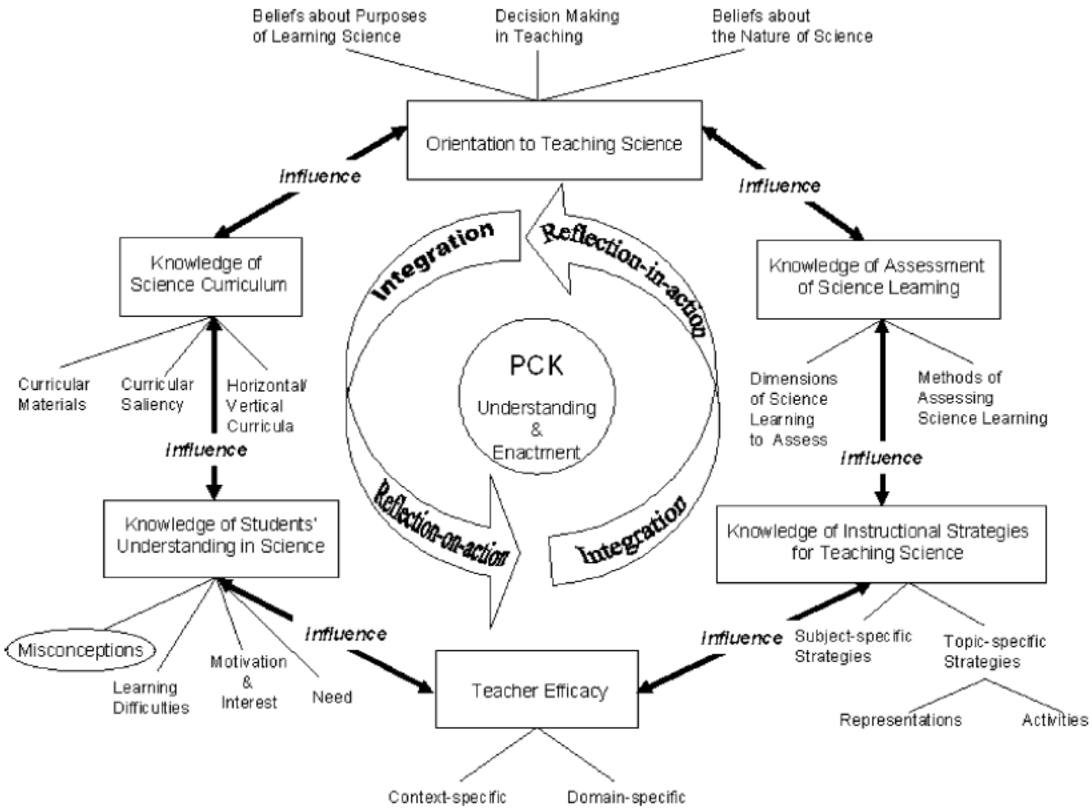


Figure 2.9: Hexagonal Model of PCK for Science Teaching (Park and Oliver (2008b).

Another model describing knowledge bases teachers need to have to teach effectively was proposed by Abell (2008). Abell's model can be understood as a modified model which integrated concepts of earlier models developed by Grossman (1990) and Magnusson et al (1999). Abell proposed four knowledge bases which included science subject matter, pedagogical knowledge, pedagogical content knowledge, knowledge of content.

Abell's science subject matter was divided into two components, namely, science syntactic knowledge and science substantive knowledge. The second knowledge base, pedagogical knowledge, comprised classroom management, learners and learning, curriculum instruction and educational aims. Abell developed five components of pedagogical content knowledge, and these are similar to Magnusson et al (1999) model components of pedagogical content knowledge. Abell’s fourth base, knowledge of content, encompasses components such as students, schools, communities and districts.

According to Abell’s knowledge base framework, science subject matter knowledge and pedagogical knowledge influence pedagogical content knowledge whereas pedagogical content knowledge and knowledge of context influence each other. But this connection became the source of weakness of Abell’s model because it is now widely accepted on the basis of empirical evidence that subject matter knowledge and pedagogical knowledge cannot affect pedagogical content knowledge without pedagogical content knowledge affecting subject matter knowledge and pedagogical knowledge.

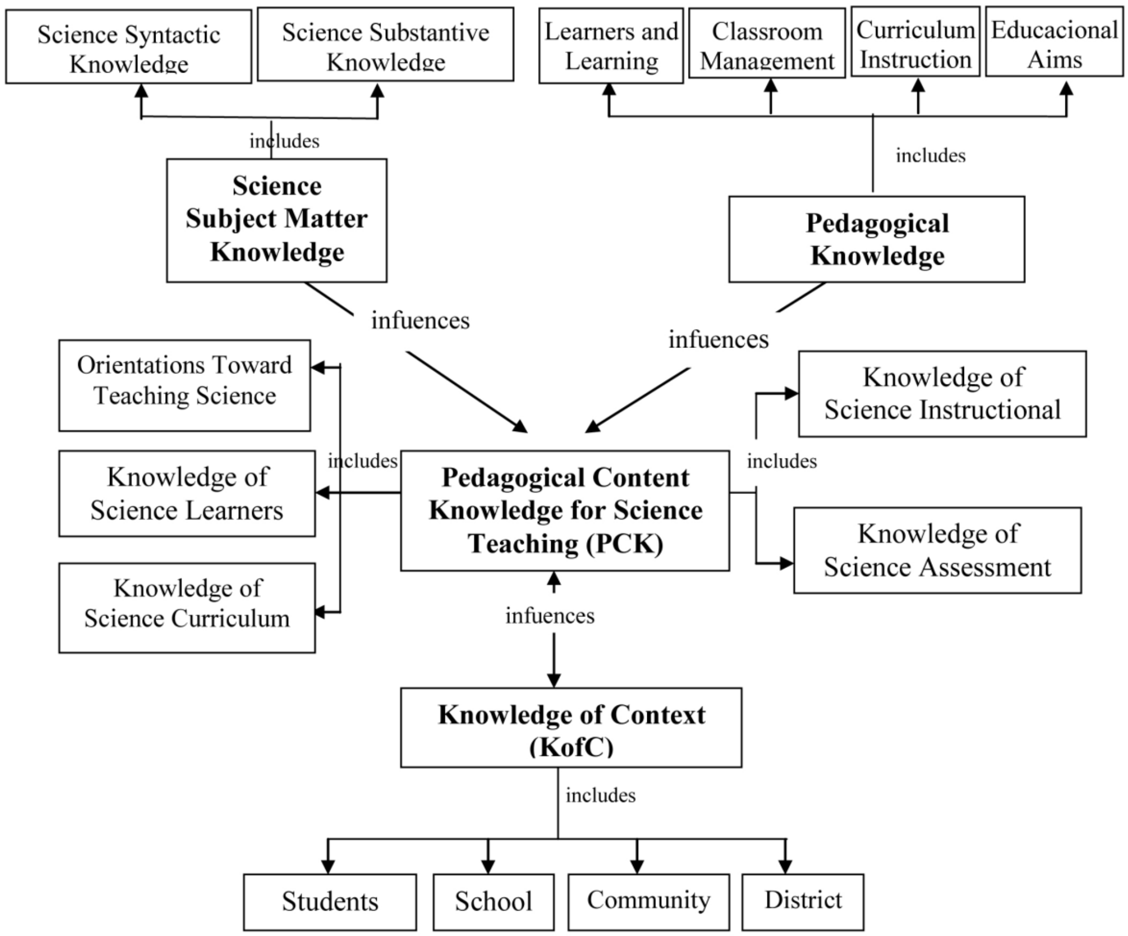


Figure 2.10: Abell's Model of Science Teacher Knowledge (From Abell, 2008, p. 1107).

As can be seen from the preceding discussion, there have been numerous studies on knowledge bases. What is remarkable about these studies is that they each reflect knowledge components and subcomponents that differ from those discussed in the other model. Thus, as can be seen from the discussion of the models in the preceding section, each model offers a different explanation of the relationship among the knowledge bases as well as among the components of the knowledge bases.

On the other hand, the knowledge bases which the models have discussed in the preceding section reflect a certain important level of commonalities. As can be seen, all models appear to agree that knowledge of content or subject matter, knowledge of teaching methods and strategies, knowledge of assessment techniques and practices, and awareness of learners and the contexts in which learning is initiated are key bases of knowledge every teacher must strive to acquire and master for teaching and learning to be successful.

Table 2.1: Different Models developed by different authors

	Knowledge Bases									
Authors	Subject Matter	Curriculum Knowledge	Students' Knowledge	Assessment Knowledge	Pedagogical Knowledge	Purposes/Orientation of teaching Science	Instructional Strategies	Context of Learning	Knowledge of Self	Knowledge of school
Shulman (1987)	A	A	B		A	A	B	A		
Tamir (1988)	A				A					
Grossman (1990)	A	B	B		A	B	B	B		A
Turner-Bisset (1999)	B	B	B			B	B	B	B	B
Magnusson et al (1999)	A	B	B	B	A	B	B	A		
Carlsen (1999)	A	B	B		A	B	B	A		A
Park & Oliver (2008a)	B	B	B	B	A	B	B			
Park & Oliver (2008b)		B	B	B		B	B			
Abell (2008)	A	B	B	B	A	B	B	A		

Note: A is a standalone knowledge base; **B** is a component of PCK; Blank means the component was not either discussed or it is not coming out clearly.

Table 2.1 summarises the different knowledge bases as they were presented by different scholars in their models. It shows that most of the scholars agreed that subject matter knowledge is a standalone knowledge base except Turner-Bisset (1999) and Park & Oliver (2008a) who had taken it as a component of PCK. Most of the researchers agreed on the components of PCK while others did not clearly explain the knowledge bases which are not marked either A and B.

However, although some of the models that have been discussed in this section specifically related the knowledge bases to science education, none of the models attempted to relate the knowledge bases to a specific topic within any science subject depending on the nature of the topic. This is to say, for example, that none of the scholars who developed these models made attempt to explain how the knowledge bases apply to the teaching of a specific topic such as biotechnology within the subject of biology. If this were present as a knowledge base in a given model, then it would be a topic-specific knowledge base. Gess-Newsome (2015) argued that the component of Topic Specific Professional Knowledge (TSPK), which can also be described as Topic Specific Pedagogical Content (TSPCK), content for effective teaching occurs at topic level and not necessarily generally at subject level. The Topic Specific Pedagogical Content knowledge (TSPCK) is a component of a knowledge base model called the PCK Summit Consensus Model (Gess-Newsome, 2015).

The PCK Summit Consensus Model is a product of the resolutions of 22 science experts in pedagogical content knowledge who convened at the 2012 conference in Colorado, USA. The aim of the conference was to resolve the discrepancies and inconsistencies in PCK models so build consensus on PCK conceptualisation. Since Shulman conceptualised his model, many thinkers built on his model to develop their frameworks, but these frameworks reflected clear discrepancies particularly in the interpretation they gave to knowledge bases and their components and subcomponents (Carlson et al., 2012). Carlson himself attested to these apparent discrepancies when he wrote:

In particular we noticed there were a significant and troubling divergences in the key elements of science PCK that drive the research and make it meaningful, including definitions, conceptual frameworks, instruments, methods, and subsequently, and the findings. p.16

The Consensus Model outlined the knowledge bases that a science teacher needs to have to teach effectively. What is interesting about the Consensus Model is that it pays attention to the Topic Specific Pedagogical Content Knowledge a teacher needs to handle specific topic effectively. The Consensus Model identifies six main levels of knowledge and these are: teacher professional knowledge bases, topic specific knowledge bases, amplifiers and filters, classroom practice, student outcomes, and another level of amplifiers and filters.

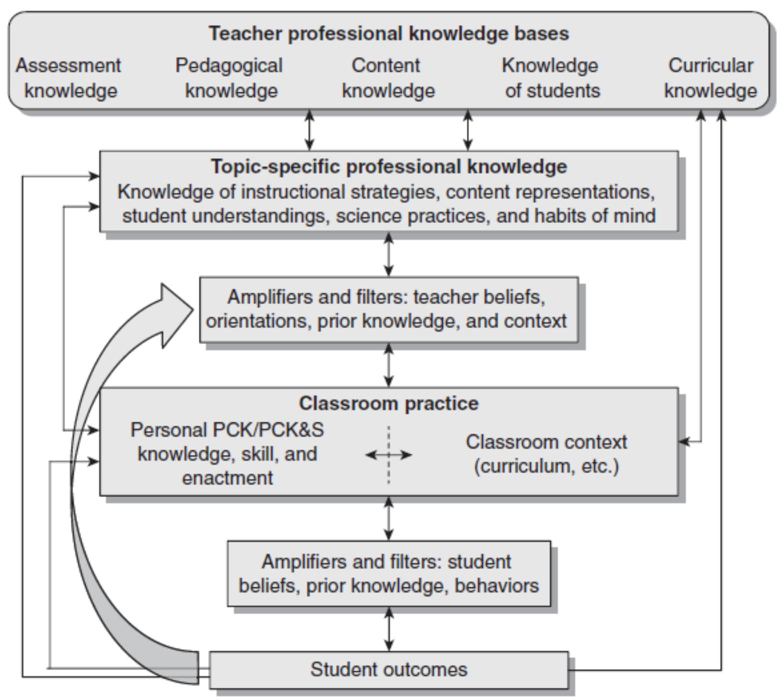


Figure 2.11: Consensus Model of teacher professional knowledge and skill, including PCK (Gess-Newsome, 2015, p. 31).

The teachers' professional knowledge base, which is the first level of the Consensus Model, comprises such knowledge bases as assessment knowledge, pedagogical knowledge, content knowledge, knowledge of students and curricular knowledge. The second level of the Consensus Model, which is topic specific professional knowledge, is composed of knowledge of instructional strategies, content representations, learners' understandings, science practices, and habits of mind. As the arrows in Figure 2.11 show, the five knowledge bases of the teacher professional knowledge level influence, and are themselves in turn influenced by, the knowledge bases outlined under the topic specific professional knowledge level.

The topic specific professional knowledge level passes through filters and amplifiers of teachers which lead to the next level of knowledge base. The filters and amplifiers consist of knowledge bases such as teachers' beliefs, orientations for teaching, prior knowledge and the context in which the knowledge is introduced.

The next level of the Consensus Model is classroom practice, which is the level at which topic specific professional knowledge is adapted and then transformed into the personal pedagogical content knowledge. At this level, the classroom practice influences and is influenced by the five main knowledge bases of the teacher professional knowledge base level.

Knowledge bases at the classroom practice level pass through filters and amplifiers of learners. The filters and amplifiers at this level consist of learners' beliefs, prior knowledge and behaviours. These filters and amplifiers are then assessed at the final level of student outcomes. According to the Consensus Model, the student outcomes influence classroom practice, topic specific professional knowledge and teacher specific professional knowledge bases.

This study used the Consensus Model because it pays adequate and specific attention to knowledge bases which science teachers need to possess at both subject and topic levels to plan and teach the subject effectively. It balances the knowledge bases of teachers with both knowledge of classroom practice and student factors that influence learning and teaching.

5.12 2.3 Theoretical framework

Shulman's model of knowledge bases has profoundly inspired subsequent models of knowledge bases that teachers need to possess to teach effectively. Many models that were developed described general knowledge bases teachers needed to possess to teach effectively, but very few models specifically related these knowledge bases to science subjects such as biology, chemistry, physics and mathematics and even to specific topics within these science subjects (Moreland, Jones, & Cowei, 2006; Ball, Thames & Phelps, 2008; Mthethwa-Kunene, Onwu & De Villiers, 2015; O'Brien, 2017).

The theoretical framework that guided this study has been adapted from Shulman's knowledge base model and the consensus model. This is the framework which the researcher used to investigate knowledge bases which biology teachers use in the teaching of biotechnology as a topic in the secondary school biology course. The framework guided the researcher's investigation of such knowledge bases as content knowledge, knowledge of students, knowledge of assessment, knowledge of curriculum and knowledge of pedagogy.

The researcher modified and adapted the consensus model to fit in the study of knowledge bases used to teach a biology topic. Levels one, two and four were considered because they were connected to the research questions of the study. However, the study did not investigate Teachers' beliefs (level three), students' beliefs (level five) and students' outcomes (level six) (see figure 2.11). The view of the researcher is that these components can form a separate study. Therefore, with reference to the consensus model, this study did not study students' performance after the topic was taught. Teachers' beliefs, whose impacts on teaching are that they profoundly influence how a teacher views teaching and knowledge, amplify or filter the information that is being taught, and affect what is taught, how it is taught, and why it is taught, are a wide area that call for a separate study as do students' beliefs and their effect on learning and performance.

The adapted framework for this study is presented in Figure 2.12. The adapted framework includes the knowledge bases of teacher professional knowledge base, whose components are knowledge of assessment, pedagogy, content, curricula and students. These knowledge bases affect and are also affected by topic specific pedagogical content knowledge, whose components are instructional strategies, content representations, curricular saliency, and students' understandings and difficulties related to the topic. All these also influence classroom practice.

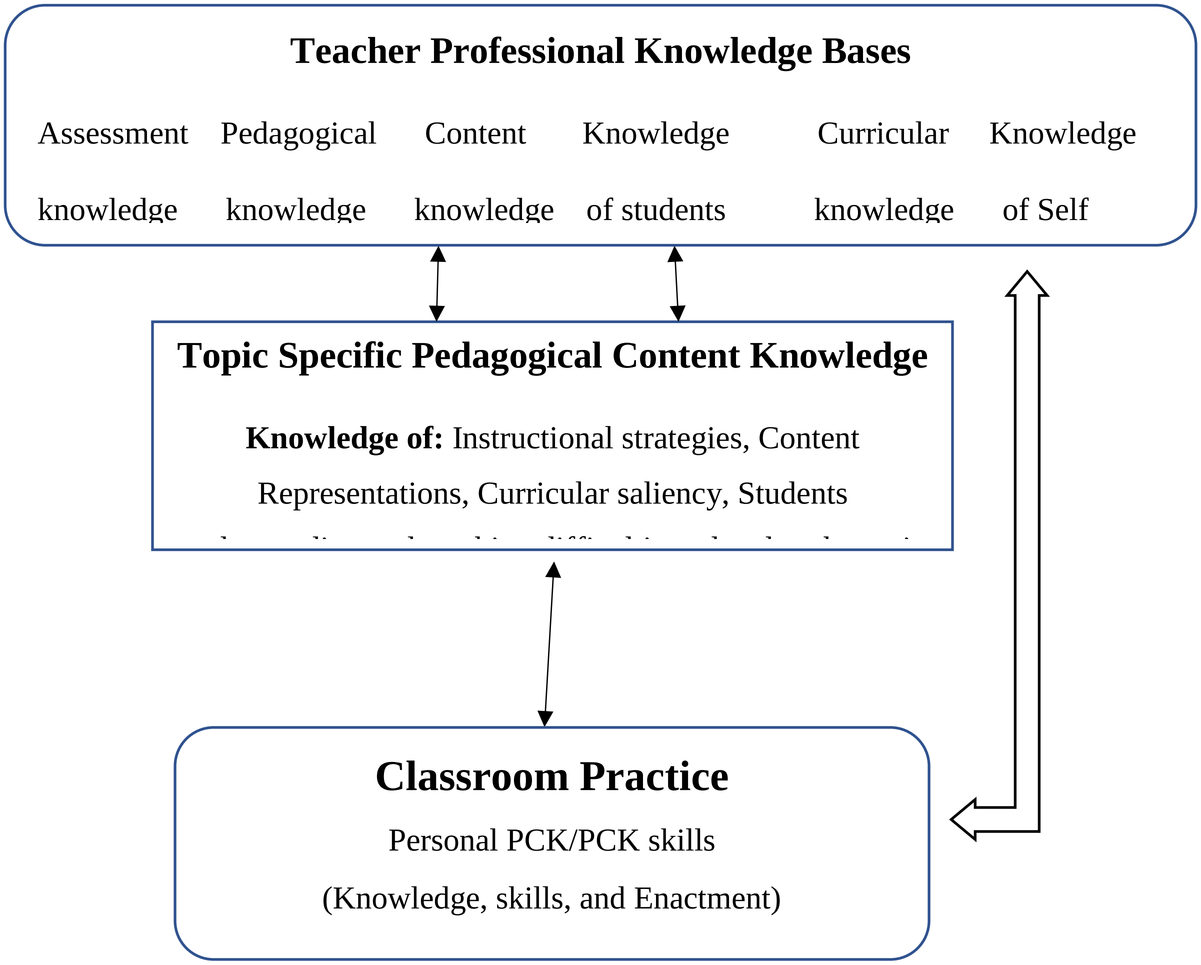


Figure 2.12: An adapted framework for Teacher Professional Knowledge

The five knowledge bases of the teacher professional knowledge base, and any other knowledge base that may be added to the model, affect topic specific pedagogical content knowledge, which is knowledge specific to a certain level, such as a class, or a specific topic within the subject, such as biotechnology in biology. For example, a teacher planning to teach biotechnology in form 4 would need to have knowledge of learners' prior knowledge and background experiences, which would influence the learners' ability to make predictions based on patterns of genetic crosses, create explanations from evidence and understand how the generation of knowledge relates to the nature of science (Gess-

Newsome, 2015). Topic specific pedagogical content knowledge can be used to construct measures, tests or rubrics to determine what teachers know about, for example, the use of content representation (CoRes) as developed by Loughran, Berry and Mulhall (2012).

2.3.1 Teacher Professional Knowledge Bases

The framework adapted for this study includes knowledge bases such as knowledge of assessment, pedagogy, content, students, and curriculum. But the framework also adds other knowledge bases, namely, knowledge of the self and knowledge of context. This is acceptable and appropriate as Gess-Newsome (2015) asserts that it is possible and acceptable to add knowledge bases to a framework especially those knowledge bases a researcher identifies in the course of the study. Knowledge of context and knowledge of self are not content-specific as they apply to the teaching of any subject.

2.3.1.1 Knowledge of assessment

Knowledge of assessment encompasses a teacher's knowledge of design and uses of formative and summative assessments and the ways in which outcomes of each assessment can be used to inform further instruction (Gess-Newsome, 2015). Assessment forms an integral component of the revised curriculum of the Malawi secondary school, and it is important that every assessment conforms to the requirements of the curriculum so as to facilitate a constructive, motivating and truly challenging learning experience to learners (MoEST, 2019). Such assessment enables learners to take stock of their progress, gauge their potential and engage remedial action to improve their learning.

Summative assessments are administered at the end of a defined learning period, such as at the end of the term or the end of an academic year. They enable teachers to determine the skills and knowledge learners have acquired over the period of their learning, and the degree to which learners have accomplished the prescribed outcomes of learning over this period. Summative assessments are used to give feedback on the performance of students to stakeholders such as parents, community, examination boards and other relevant institutions that need these results to make decisions. They are also used to make decisions that affect the placement and classification of learners, to provide mechanisms for quality control, and to provide teachers and schools with means for evaluating their teaching over a period of time so they can set self-improvement goals in case of the self-evaluation revealing some inadequacies (MoEST, 2019).

Formative assessments, on the other hand, enable teachers to monitor learners' progress in the acquisition of skills and knowledge, identify gaps in knowledge and skills, and give timely feedback to help learners meet learning goals. While summative assessments are administered at the end of a defined learning period, such as at the end of an academic term or an academic year, formative assessments are regularly and frequently administered, such as at the end of a topic, weekly or monthly. Formative assessments are important in that they quickly and timely draw the attention of teachers to areas where learners need more help and those which learners understood very well. This enables teachers to reflect on their teaching approaches in future, address gaps and lapses in learning quickly, build learners' confidence in their ability to learn, and inspire learners to take responsibility for their own learning as they expect to be assessed regularly (MoEST, 2019).

2.3.1.2 Pedagogical knowledge

Baumert et al. (2010) identified five main components of pedagogical knowledge in their model. These are knowledge of classroom management, knowledge of teaching methods, knowledge of assessment methods, knowledge of classroom assessment, and adaptivity.

Knowledge of classroom management incorporates a teacher's ability to maximise instruction time, manage classroom events, teach at a steady pace which engages learners throughout the process, and maintain clear direction throughout the lesson. Knowledge of teaching methods, on the other hand, entails a teacher's mastery and command over teaching methods available to them, as well as the ability to select and engage teaching methods that are suitable to the nature of the content being taught. This also concerns a teacher's awareness of how to use each of the methods available to them.

Knowledge of classroom assessment requires that a teacher be conversant with various types of assessments and their purposes and uses. Thus, a teacher must know the uses of a formative assessment and a summative assessment and be able to administer them with effectiveness. A teacher also needs to be familiar with the different frames of reference (for example, social, individual and criterion-based) and how each one of them influences students' motivation. A teacher's ability to create assessments and to put them to best use is even enhanced by their awareness of how to structure learning objectives, their familiarity with the lesson process, lesson planning, and lesson evaluation. The difference between Baumert et al's model and the consensus model in the way they treat knowledge of assessment is that Baumert et al's model considers knowledge of assessment as a component of knowledge bases, while the consensus model considers knowledge of assessment as a standalone knowledge base and not as a component. The adapted model studied knowledge of assessment as a standalone knowledge, where only formative assessment was considered, as learners were not given any summative assessment.

Adaptivity, the final component of Baumert et al pedagogical knowledge, concerns the ability of the teacher to deal with heterogenous situations in the course of their teaching.

Geiss-Newsome (2015) described pedagogical knowledge as all strategies teachers use for classroom management and student engagement. These include, for example, question and answer techniques, how to design a lesson plan, and instruction strategies to support differentiation according to student needs. It is important to understand, however, that teaching is a complex process which involves interactions between the student and the teacher, the student and the content, the student and another student, and the student and their immediate environment. On the part of the teacher, teaching engages the teacher with the content and the environment in addition to the teacher's involvement with their learners.

Therefore, in light of these multifaceted interactions, it is critical for teachers to demonstrate competence in the design or planning of lessons and assessments to influence interactions that will yield effective impact. During the planning and design stage, a teacher must be able to identify and incorporate teaching and assessment strategies that are appropriate to both the content that will be taught and the level of learners who will learn the content. It is also important for the teacher to consider incorporating teaching methods that promote participatory learning. Participatory methods of teaching are crucial to the process of learning as they facilitate a practical dimension of learning, that is, create an opportunity for learners to translate what they learn into action. Teachers can select from a range of teaching methods and strategies which the secondary school curriculum for each subject prescribes for them.

2.3.1.3 Content knowledge

Content knowledge is a term used to describe all the rules, structure and methods used to generate knowledge or information about the topic a teacher plans to teach learners (Gess-Newsome, 2015).

Seen in this light, content knowledge is the academic content of the discipline or topic (Mavhunga & Rollnick, 2016). Content involves acquaintance with and mastery of facts, theories, concepts, ideas, and terminology relating to a specific topic (World Bank Group, 2017). A teacher's knowledge of content is critical for high impact learning as empirical research has shown that students' performance is to a greater degree influenced by a teacher's quality in terms of content mastery and pedagogical knowledge more than students' prior academic record or the type of school they attend (Udofi & Ishola, 2017). Thus, content knowledge is the most important knowledge base every teacher must strive to acquire in order to teach effectively.

The fact that knowledge of content appears as a knowledge base in apparently all teacher knowledge base models, experts have developed clearly underlines the critical importance of content mastery to the potential of every teacher to handle subjects with ease and effectiveness. In fact, content mastery remains the key for every teacher to keep abreast with emerging issues and trends in science as knowledge continues to evolve rapidly and swiftly in the fields of science and technology and as new knowledge and discoveries continue to be incorporated in the curriculum. It is for these reasons that the thesis examines how biology teachers' content knowledge and other knowledge bases, such as pedagogical content knowledge and knowledge of the curriculum, affect their teaching of biotechnology, which is a new topic in the curriculum under the core element of genetics and evolution.

2.3.1.4 Knowledge of students

Knowledge of students looks at how students learn and their interests and aspirations in addition to their preferences (Mphathiwa, 2015). It further focuses on students' prior knowledge, their conceptions and preconceptions, as well as their differences in order to inform modifications of instructional material (Shulman, 1987). For Aydin et al (2014), knowledge of students involves a teacher's awareness of learners' difficulties, their misconceptions, and the prerequisite knowledge that students should have before introducing a new topic. The importance of a teacher's awareness of their students' learning difficulties, preconceptions and misconceptions, and the knowledge students need to have to understand a new topic is that it enables teachers to prepare and engage relevant illustrations or representations and activities that make their teaching effective (Van Driel, Berry & Meirink, 2014).

2.3.1.5 Knowledge of curriculum

A curriculum comprises all the selected, organised, integrative, innovative and evaluative educational experiences provided to learners consciously or unconsciously under the school authority to achieve the designated learning outcomes which are achieved as a result of growth, maturation, and learning meant to be best utilised for life in a changing society (Mulenga, 2018). The curriculum represents the intent of the education system in a country and carries most of the beliefs, values, attitudes, skills, knowledge and all that education is about (Mulenga, 2018).

Curricular knowledge comprises the knowledge of programs, resources and instructional materials designed for teaching specific topics (Shulman, 1986). It includes the goals of the curriculum, curriculum structures, the role of a scope and sequence, and the ability to assess a curriculum for coherence and articulation. Curricular knowledge is vital as it supports the formulation of connections between topics and as it provides necessary scaffolding for future learning (Lankford, 2010). A teacher's knowledge of the curriculum is critical for its successful implementation and for enhancing its usefulness to the society.

The role of government must be to plan and conduct periodic curriculum orientations in order to familiarise teachers with the goals, objectives and specific content of the curriculum. These orientations will be key to equipping teachers with the knowledge and skills they need to help them plan, implement and evaluate their teaching in line with standards and objectives prescribe in the curriculum. For example, the Ministry of Education, Science and Technology (MoEST) conducted two curriculum orientations in 2014 and 2019 to address gaps in knowledge and skills. However, biotechnology as a new topic in the curriculum was targeted because it was the only topic which was new in the second orientation done in 2019 after it was also covered by SMASSE Inset in 2018.

2.3.2 Topic-Specific Pedagogical Content Knowledge

A discussion of Topic Specific Pedagogical Content Knowledge as a concept relates to the current study as one of the objectives of the current study was to investigate biology teachers' understanding of biotechnology and how teachers teach biotechnology. The aspects of Topic Specific Pedagogical Content include curricular saliency, instructional strategies, content representations, student understanding, and the teaching of difficult concepts (Gess-Newsome, 2015).

Having content knowledge or having pedagogical knowledge does not amount to having Pedagogical Content Knowledge (PCK). This implies that Pedagogical Content Knowledge (PCK) is more than the sum of its parts as PCK is composed of other knowledge bases in addition to content knowledge and pedagogical knowledge (Smith & Banilower, 2015). But content knowledge remains the central aspect of pedagogical content knowledge as pedagogical content knowledge is always specific to a subject such as biology, and to a topic within a subject such as biotechnology in biology, and even to a specific concept within a topic and subject such as genetic engineering under biotechnology and biology (Hashweh, 2005). Rollnick and Mavuhanga (2016), recommending the need to take into consideration specific components of pedagogical content knowledge when teaching a particular topic, identified the five components of PCK which teachers need to take into account, namely, student's prior knowledge, curriculum saliency, what makes the topic easy or difficult, representation that include powerful examples and analogies, and conceptual teaching strategies. These components are analogous to components of the Teacher Specific Pedagogical Content Knowledge of the consensus model.

2.3.2.1 Instructional strategies

Instructional strategies refer to the effective teaching approaches prescribed for a given topic, in the context of this topic, instructional strategies refer to those teaching approaches for successfully teaching biotechnology as prescribed in the Malawi secondary school biology curriculum. Instruction strategies prescribed for teachers are based on the understanding that the process of teaching involves different levels and forms of interaction for it to be meaningful and successful both to the teacher and to the student. These levels and forms of interaction include those between the student and the teacher, the student and the content, the student and another student, the student and the environment, the teacher and the content and, finally, the teacher and the environment.

The success of every teacher depends on the teacher's mastery and ability to successfully engage with these different levels of interaction. It also depends on the teacher's ability to select suitable strategies for instruction, and these vary depending on the nature and depth of the topic and, at times, the level of knowledge and experience of learners involved in the process. Again, a teacher's success with using certain instruction strategies depends on their mastery of, and ability to, use the selected instruction strategies.

The Malawi secondary school curriculum suggests, and therefore strongly recommends the use of, participatory teaching methods because of their potential to facilitate truly practical and meaningful learning on the part of learners. These participatory instruction strategies include such approaches as group work, explanation, demonstration, group assessment, individual appraisals, and oral and written exercises. These learner-centred teaching strategies are further reinforced by the use of different teaching and learning resources such as Information, Communication and Technology (ICT) tools, wall charts, textbooks, resource persons, the local environment, and the learners themselves (MoEST, 2013).

Loughran, Berry & Mulhall (2004, 2006 & 2012) developed Content Representation (CoRe) as a tool to assess teacher's pedagogical content knowledge. Content Representation (CoRe) has eight prompts which share similarities with components of Shulman's knowledge bases. These eight prompts include: (a) what you intend the students to learn about this idea; (b) Why is it important for students to know this? (c) What else you know about this idea (that you do not intend students to know yet)? (d)

Difficulties/limitations connected with teaching this idea; (e) Knowledge about students' thinking which influences your teaching of this idea; (f) Other factors that influence your teaching of this idea; and (g) Teaching procedures (and particular reasons for using these to engage with this idea). Therefore, the eighth prompt (h), "Teaching procedures" and "Ways of ascertaining students' understanding or confusion around this idea" links to this component of teaching or instructional strategies (Mavhunga & Rollnick, 2016). However, in the theoretical framework, content representation has a different meaning which has been defined in the subsequent subsection. There is a strong link between teaching procedures, which is one of the prompts of Content Representation (CoRe).

2.3.2.2 Content representations

Content representations, a component of TSPCK, stand for illustrations or activities for a specific topic. Content representations for a topic may include diagrams, photographs, simulations, tables and use of oral or written presentations (Gess-Newsome, 2015). Content representations form the basis of topic-specific teaching strategies and, therefore, describes the way teachers think about the knowledge required to teach a specific topic in a given class (Mphathiwa, 2015). Using content representations in teaching a topic requires a teacher's ability to recognise and link learners' prior knowledge, experiences and misconceptions to the topic the teacher is teaching. When planning to teach genetic engineering, for example, the teacher may consider incorporating pictures or simulation to help them demonstrate the process of genetic engineering.

2.3.2.3 What makes a topic easy or difficult

What makes a topic easy or difficult to teach links with the fourth prompt of content representations (CoRes) which is "difficulties/limitations connected with teaching this idea" (Mphathiwa, 2015; Mavhunga & Rollnick, 2016). This component describes the challenges a teacher anticipates to face when teaching a given topic. For example, genetic engineering process in biotechnology.

2.3.2.4 Knowledge of students' prior knowledge and the difficulties related to the teaching

Knowledge about students' thinking that influences a teacher's teaching of a given idea is the fifth prompt of Loughran et al's (2004, 2006, 2012) content representation (CoRe). This prompt of content representation is linked to the learners' prior knowledge in the TSPCKs consensus model (Mavhunga & Rollnick, 2016).

According to Loughran et al (2012), successful teachers build their lessons around what learners already know about the topic from their prior experience and knowledge and also factor into their planning the specific teaching and learning conditions established through the topic. As in the case of biotechnology, for example, teachers integrate crosscutting concepts within the topic, what learners already know about the topic as well as the misconceptions about the topic. For example, students are expected to know the structure of a bacterium, chromosomes, genes and deoxyribonucleic acid (DNA) if they are to understand how recombinant DNA is formed.

2.3.2.5 Curricular saliency

Curriculum saliency describes the process of deciding what is important for teaching and sequencing when teaching a topic (Mavhunga & Rollnick, 2016). This involves the ability of the teacher to identify what to teach, what to emphasise in each lesson, and what to leave for later. Mavhunga & Rollnick (2016) link curriculum saliency with the first three prompts of content representation, namely, (1) what do you intend students to know? (2) why is it important for students to learn this? (3) what additional information do you know on this topic which you do not want students to know yet?

The first prompt helped the researcher to find out biology teachers' understanding of what matters in a particular content area while the second helped the researcher to find out the decisions biology teachers make when planning to teach a particular content which they know to be important to students' everyday lives (Loughran et al, 2012). The third prompt tries to find out what the teachers know about a particular concept or topic and how much they are to teach the students (Loughran et al, 2012). According to Laughran et al, 2012, this prompt influences the teachers' thinking in relation to the fourth prompt which looks at difficulties or limitations connected with teaching the content.

2.3.3 Classroom practice

The interaction of personal Pedagogical Content Knowledge and the classroom context occurs in the classroom (Gess-Newsome, 2015). Personal Pedagogical Content Knowledge, according to this study, is described as the knowledge of reasoning and planning for the teaching of a specific topic such as biotechnology to ensure that students understand all the concepts in the topic. Thus, the final specific research question of this study sought to find out how teachers of Biology plan and implement their lessons so that they are able to use their knowledge bases effectively.

5.13 2.4 Teaching strategies for biotechnology

Teaching strategies, also known as teaching methodologies, are crucial for effective lesson delivery, helping students understand the content being taught. The teaching of biotechnology, a complex and specialized subject, requires specific strategies. A review of research by Hin, Yasin, & Amin (2019) in Malaysia highlights various strategies used worldwide in biotechnology education.

The first teaching methodology for teaching biotechnology Hin et al (2019) identified through their reviews is cooperative learning. This teaching strategy is commonly used in classrooms where students are required to work in small groups (Wahab, 2020). It may also be involved in laboratory sessions and in learning activities which require learners to discover solutions to problems or answers to questions by themselves (Hin, 2019). According to Wahab (2020), under cooperative learning, students of different abilities are organised into small groups to work on activities that will improve their understanding of the concept or subject. This is effective as students in the groups take responsibility for their learning as well as for the learning of their peers.

The second teaching methodology for teaching biotechnology, Hin et al. (2019), through their review, identified modelling as one of the teaching methodologies. The emphasis of modelling as a teaching strategy is on constructing and applying conceptual models and physical phenomena (Hin et al., 2019). This method helps students engage in scientific discourse and debate on topics like cloning or genetically modified organisms, enhancing their ability to understand and discuss complex biotechnological concepts.

Fiksl, Flogie, & Abersek (2017) justified the critical role that increased student interest, a welcoming environment, and active participation play in the learning process. The fourth industrial revolution calls for innovation in education, which Sadler et al. (2015) describe as new pedagogical concepts, methodological approaches, instructional techniques, or teaching tools that improve teaching and learning outcomes. Innovative approaches, including research inquiry, problem-solving, project-based learning, argumentation, virtual experiments, and web-based interdisciplinary learning, have been shown to positively impact laboratory experiences (Orhan & Sahin, 2018).

Integrating Information and Communication Technology (ICT) into biotechnology lessons proves very effective (Hin et al., 2019). ICT tools like YouTube and advanced organisers help students grasp biotechnology concepts more easily and increase their motivation to learn (Bonde et al., 2014). Virtual laboratory work, enabled by ICT, allows students to master skills and understand knowledge without the need for expensive chemicals and equipment. YouTube animations, for instance, can help students visualize and comprehend microscopic processes within cells.

A study by Kooffreh, Ikpeme, & Mgbado (2021) in Nigeria found that secondary school students had limited understanding and interest in biotechnology. To address this, the study recommended increasing awareness and emphasizing biotechnology applications. This can be achieved by adopting innovative teaching and learning methods. Fiksl, Flogie, & Abersek (2016) found that using problem-based learning, research-based learning, and participatory learning techniques, supported by ICT, improved students' interest in Science, Technology and Engineering (STE) subjects. These methods enhanced classroom climate, personal development, organisation, interest in the material, and overall student well-being.

Applying these innovative methods in Malawian schools can improve biotechnology education. By incorporating web-based experiments and virtual game-based applications, students can engage more interactively with biotechnology concepts, processes, and applications, leading to better understanding and increased interest.

5.14 2.5 Overview of studies that used the Consensus Model

Liepertz and Borowski (2018) explored the Consensus Model in the context of physics education. They investigated the relationships among physics teachers' professional knowledge, the interconnectedness of content structure, and student achievement. Their study aimed to understand how various professional knowledge bases of teachers influence their in-class actions and subsequently impact student achievement. Using a sample of 35 physics teachers and their classes, the researchers collected data through paper-and-pencil tests administered to both teachers and students, and by videotaping and analysing one lesson taught by each teacher. Through their study, Liepertz and Borowski concluded that the interconnectedness of content structure is an important indicator of instructional quality. They further deduced that teachers' professional knowledge bases (TPKB), such as Content Knowledge (CK) and Pedagogical Knowledge (PK), impact Topic-Specific Professional Knowledge (TSPK), represented by the teachers' Pedagogical Content Knowledge (PCK).

Nxumalo-Dlamini & Gaigher (2019) used the consensus model to find out how teachers used computer-based simulations in teaching electrolysis in Eswatini. Their study used levels two, three and four of the consensus framework’s six levels which directly affected the research questions. The study models the transformation of teachers’ professional knowledge in the topic electrolysis, amplified and filtered by their views and beliefs about using CBS, into classroom practice. In their study, the first level represents broad teacher professional knowledge bases, and the last two levels involve learning amplifiers and filters and learner outcomes. The study was located within the interpretive paradigm and a qualitative case study was used. Three chemistry teachers were purposively sampled whose lessons were observed. They were also given questionnaires and interviewed before and after the lessons. The findings of the study showed that teachers' attitudes acted as amplifiers and filters towards CBS. The study also found that teachers who made mistakes were due to various school departments, where some teachers work in isolation. The main conclusion of the study was that teachers' views about CBS largely influenced the way the teachers used CBS in the classroom and that teachers' PCK and SMK are important factors optimizing the learning experience.

Mphathiwa (2015) carried out a study in social studies which targeted a specific topic PCK of a topic which used a PCK consensus model (2015). The study incorporated the categories of teacher professional knowledge bases (Level one), Topic Specific Pedagogical Content Knowledge (Level two) and teachers' beliefs which acted as amplifiers and filters (level three) which influence classroom practice (level four). The data collection was done through questionnaires, belief tests, Content Representations (CoRes) and lesson planning. Her research established that there exists a relationship between teachers' knowledge of the topic to be taught, their beliefs and their ability to change content knowledge into a form that is appropriate for teaching. The findings of the study showed that the teachers' understanding of what it means to teach effectively focused on the role of providing care and backgrounds to the mediation of knowledge. Although teachers were well able to describe students' prior knowledge, they struggled to articulate how the topic fitted into the curriculum, what constituted appropriate representations (illustrations) of the key issues and which teaching strategies would be most appropriate. The findings also showed that, although the teachers possessed knowledge about the topic, they did not design lessons that provided opportunities for links between students' experiences in their communities. They developed lessons that provided subject teaching strategies that were not specific to the topic.

The use of content representation (CoRe) enabled Mphathiwa (2015) to find out how the teachers would present the whole topic in class as she was not able to observe the lessons. Therefore, the same instrument was used in this study to find out how the teachers would present the topic, biotechnology, as only two lessons observed were analysed, and they had prepared seven lessons.

5.15 2.6 Overview of studies that looked at Pedagogical Content Knowledge

Mthethwa-Kunene, Onwu, & Villiers (2015) used a qualitative approach within an interpretive paradigm and a multiple case study method to explore biology teachers' Pedagogical Content Knowledge (PCK) in teaching genetics in Swaziland. The study used Pedagogical Content Knowledge as a theoretical framework. The study engaged four participants who were selected based on their schools' performance and recommendations from school principals and science inspectors.

The study found the biology curriculum to be the most influential determinant of the teachers' PCK, serving as both a knowledge source and organiser. The study also revealed that teachers lacked knowledge of students' preconceptions in genetics despite demonstrating strong content knowledge and pedagogical knowledge. Also, the researchers observed that no experiments were conducted due to resource limitations, despite the schools being fairly resourced. Thus, in light of these findings, the study recommended the need for teachers to use reflective journals to help them develop critical thinking and strengthen their teaching methodologies (Dynment & O’Connell, 2006).

The only limitation of this study, however, is that the study used three teacher knowledge bases only (that is, content knowledge, PCK, and pedagogical knowledge). The researcher feels the study would have made a stronger case if it had used the consensus model, which has five knowledge bases and topic-specific pedagogical content knowledge. This is because the consensus model resonates well with the topic-specific pedagogical content knowledge in as far as what happens in a classroom during a lesson is concerned. During a lesson, a teacher's topic-specific pedagogical content knowledge matters as it influences and is influenced by Teacher Professional Knowledge Bases (TPKBs), and in turn influences the lesson.

Another study carried out by Mim, Rahman, & Jahanara (2017) examined the PCK of four teachers using the Content Representation (CoRe) template on genetics. This study examined the PCK of four teachers using the Content Representation (CoRe) template on genetics in Bangladesh. Employing a case study approach, the study sought to reveal the existing nature of PCK and the level of PCK among teachers through the CoRe template.

The study found that teachers were not fully aware of the latest national curriculum, although they demonstrated sufficient knowledge of genetics. Also, the researchers noticed that teachers mostly used lecture methods despite the curriculum's emphasis on learner-centred methods such as inquiry methods. The study also observed that students were primarily assessed through recall questions. In addition, the study also found that most teachers did not use appropriate teaching materials during lessons.

Bravo and Cafre (2016) investigated biology teachers' PCK in teaching human evolution in schools in Chile. Like Mthethwa et al. (2015), Bravo and Cafre included participants who graduated from the same university. However, unlike the participants whom Mthethwa-Kunene et al used, participants in Bravo and Cafre’s study did not have adequate knowledge of evolution as they had not learned genetics and evolution during their university days. The study organised the participants into pairs, each of which was asked to plan a similar lesson together. Each of the members of the pair was then asked to deliver the same lesson in different classrooms.

Through Bravo and Cafre’s study, participant teachers improved their knowledge of the content of evolution and learned effective methods for teaching evolution. In addition, participant teachers became aware of critical misconceptions learners held about evolution as well as the difficulties they faced in understanding the topic. Finally, and of critical significance, participant teachers appreciated the critical role of reflection journals in effective lesson planning and preparation, in critiquing lessons that have been delivered, and in helping teachers identify suitable teaching strategies.

Chan & Yung (2017) conducted a qualitative case study adopting an interpretive paradigm to understand how teachers create new instructional strategies and perceptions of the topic, especially when they were not fully aware of the learning difficulties which the students possessed. The study involved two experienced teachers in Hong Kong to explore how their Pedagogical Content Knowledge (PCK) developed while teaching a new science topic, polymerase chain reaction (PCR), for the first time.

In the study, Chan and Yung discussed how teacher’s PCK develops from the pre-lesson planning stage, through the interactive teaching stage, to the post-lesson reflection stage based on the four PCK components. These four PCK components were knowledge of students (KS), knowledge of instructional strategies, and knowledge of assessment as they are reflected in the Magnusson et al. (1999) model. The four components of the Magnusson Model, which they used in their study, differed from the knowledge bases of the Consensus Model (2012).

Chan and Yung's study made interesting discoveries relating to the teaching of new and challenging topics. Firstly, the study revealed that teachers' previous experiences greatly influenced how they planned to teach the new topic. The researchers discovered that one of the two teachers purposefully integrated two pedagogical strategies in his lesson planning based on his understanding of students' prior knowledge, which informed his PCK development. This deliberate attention facilitated the integration of various PCK components, such as Knowledge of Assessment, Knowledge of Students, and Knowledge of Instructional Strategies and Representations, at different stages of planning and teaching.

The findings suggested that Subject Matter Knowledge (SMK) can either promote or hinder PCK development, depending on the way it is applied by teachers. Thus, in light of these findings, the study recommended that curriculum developers and other stakeholders recognise that enhancing teachers' SMK alone may not suffice for effectively preparing them to teach newly introduced topics.

In another research study conducted in Turkey, Aydemir (2014) investigated science teachers' content knowledge and pedagogical content knowledge on genetics. The study focused on teachers' knowledge of curriculum, knowledge of students, and knowledge of teaching strategies. Five experienced science teachers from five different schools were involved in the study. Each of the five teachers had to teach genetics to 8th grade students. The study, thus, collected data through classroom observations, a test on genetics, and pre- and post-PCK interviews.

The study found that participating teachers lacked adequate understanding of basic concepts in genetics and that they often taught concepts that were beyond the curriculum objectives. Also, all teachers exhibited limited knowledge of suitable teaching strategies for addressing learners' learning difficulties and misconceptions. This was manifested by the teachers' overreliance on explanation as a strategy for overcoming learners' learning difficulties and misconceptions. On the other hand, the study observed that all teachers in the study demonstrated strong knowledge and awareness of the needs and difficulties of their learners as far as learning genetics was concerned.

Aydemir's study investigated specific knowledge bases. This approach differs sharply from the present study which aimed to investigate the knowledge bases used by biology teachers in teaching biotechnology. This approach highlights a difference in the scope and focus of the two research studies, with Aydemir's work concentrating on predefined knowledge bases in genetics education and the other study exploring the broader application of knowledge bases in biotechnology.

5.16 2.7 Overview of knowledge bases for teaching biotechnology

Biotechnology is a complex field encompassing scientific, technological, sociological, and ethical dimensions (Moreland, Jones, & Cowie, 2006). It is widely held as one of the century's highly important scientific and technological revolution (Gorritz & Velazquez, 2009). But biotechnology as a topic of study poses various challenges for teachers at all levels of education across different countries. This claim is reinforced by findings of a number of empirical studies some of which are discussed in this section.

A survey study conducted in selected schools of New South Wales, Australia, revealed that complexity of subject matter and a lack of practical work to teach the content better hindered effective teaching of biotechnology at the secondary school level (Steel & Aubusson, 2004). Another study involving secondary school science teachers in India discovered that biology teachers possessed low content knowledge of biotechnology (Srutirupa and Mohalik, 2013). In light of the serious inadequacies of knowledge of content of biotechnology teachers of biology possessed, the study recommended the need for refresher courses to improve teachers' conceptual knowledge of biotechnology and awareness of teaching strategies.

In the USA, a study by Orhan and Sahin (2018) also reported serious knowledge deficiencies of biotechnology among university students. The study further discovered that although pre-service teachers confessed that they were aware of applications of biotechnological processes, they, however, struggled to answer questions about the biotechnological processes accurately. This was also evident in Turkey, where Gürkan and Kahraman (2018) found that preservice teachers had various misconceptions about biotechnology. These misconceptions were related to genetic engineering, genetically modified organisms and cloning. In the Malawian context, too, the Ministry of Education, Science and Technology offered in-service training to biology teachers in 2108 to address gaps in knowledge of biotechnology having anticipated the struggles teachers of biology would likely face in teaching biotechnology which had just been introduced in the biology curriculum (DTED, 2018). The content of the topic was provided including the teaching strategies different activities they could carry out for specific concepts and how to design classroom activities of the topic.

Yasin, Amin and Hin (2018) investigated the challenges which teachers and students faced with teaching and learning biotechnology in Malaysian secondary schools. Their study unearthed vital problems which teachers and learners faced with biotechnology. The problems included lack of reference books and teaching aids, and inadequate content knowledge of biotechnology. They used the findings of their study to emphasise the importance of integrating 21st-century skills to enhance students' scientific literacy in biotechnology. To address problems relating to content knowledge, the researchers recommended the need for refresher courses for teachers to improve their content knowledge and teaching strategies. They also underscored the need for more research to identify the specific problems faced by teachers which, as stated by Mim, Rahman and Jahanara (2017), would go a long way in enhancing science teachers' PCK.

Similarly, another study by Moreland, Jones and Cowie (2006) conducted in New Zealand found biotechnology to be the most challenging area to teach. The study tipped teacher content knowledge as a crucial factor in facilitating student learning. The study involved six primary school teachers from four different schools. The teachers collaborated in a workshop to develop teaching and learning materials and lesson plans. The aims of this collaborative approach were to ensure shared knowledge of biotechnology and to explore effective teaching strategies.

Moreland, Jones and Cowie's study identified seven key areas of knowledge bases for teaching biotechnology. These seven key areas included:

1. Nature and characteristics of biotechnology.
2. Conceptual, procedural, societal, and technical aspects of the subject.
3. Knowledge of the curriculum, including goals, objectives, and specific programs.

4. Knowledge of student learning in the subject, including existing knowledge, strengths, weaknesses, and learning progression.
5. Specific teaching and assessment practices for the subject.
6. Understanding the role and place of context in teaching.
7. Classroom environment and management in relation to the subject.

However, this study focused on primary school teachers, indicating a need for similar research on secondary school teachers. Therefore, conducting a study on secondary school biology teachers in Malawi could provide insights into the knowledge bases and challenges specific to this educational level as there is no biotechnology in the primary school curriculum in Malawi.

5.17 2.8 Knowledge bases used in this study

After reviewing the literature on knowledge bases, including Pedagogical Content Knowledge (PCK), Teacher Professional Knowledge Bases (TPKB), and Topic-Specific Pedagogical Content Knowledge (TSPCK), this study's conceptualization and execution were theoretically informed by the PCK Summit Consensus model. This model emphasises the integration of practice within PCK and endorses the amalgamation of various knowledge bases to produce effective classroom implementation of PCK (Gess-Newsome, 2015).

The PCK Summit Consensus model highlights the importance of five key knowledge bases:

1. Assessment knowledge

2. Curriculum knowledge
3. Content knowledge
4. Knowledge of students
5. Pedagogical knowledge

Additionally, the model includes all sub-components of topic-specific pedagogical content knowledge (Gess-Newsome, 2015). However, it is acknowledged that these five knowledge bases may not be exhaustive. Turner-Bisset (1999) suggested that knowledge of self could also be considered a professional knowledge base for teachers.

Given that Teacher Professional Knowledge Bases (TPKB) represent the knowledge bases for the profession, it was assumed that all teachers participating in this study had well-developed knowledge bases due to their extensive teaching experience (over ten years). This experience, whether in primary or secondary teacher education, likely contributed to their robust knowledge bases.

According to Gess-Newsome (2015), within the same consensus model, teachers possess topic-specific PCK for each subject they teach, enabling effective instruction. The focus of this study was to investigate how secondary school biology teachers utilise their knowledge bases in teaching biotechnology, a specific and newly introduced topic in the senior biology secondary school curriculum.

5.18 2.9 Summary of the chapter

This chapter reviewed literature-related studies conducted in various countries on knowledge bases such as subject matter knowledge, pedagogical content knowledge, curriculum knowledge, and knowledge of learners. These were discussed within the frameworks of different models used to study PCK and other knowledge bases. The models reviewed include:

- Grossman (1990) model
- Magnusson et al. (1999) model
- Turner-Bisset (1999) model
- Carlsen (1999) model
- Park & Oliver (2008) model
- Abell (2008) model

The chapter also examined various studies on different topics, including biotechnology within biology and other science subjects in secondary schools. It presented different methodologies used to achieve the objectives of these studies. Most of the studies focused on a few knowledge bases, while this study investigated a broader range of knowledge bases that biology teachers use in teaching a specific topic like biotechnology.

The literature review highlighted several important issues regarding the appropriate methodologies for studies examining knowledge bases. In the context of this study, it was noted that the identified knowledge bases directly affect teaching strategies, PCK, general pedagogical knowledge, and other aspects crucial to teaching biotechnology. Therefore, this study proposes using an adapted consensus model, also known as the Model of Teacher Professional Knowledge and Skill (TPK&S), to investigate the knowledge bases biology teachers use and how they apply them in teaching biotechnology concepts based on the MSCE biology curriculum.

The adapted theoretical framework of the consensus model includes:

- Teacher professional knowledge bases
- Topic-specific pedagogical content knowledge
- Classroom practice

This framework was employed to address the main research question and the five specific research questions of the study. The next chapter will present the research design and methodology used in this study.

CHAPTER THREE

RESEARCH METHODOLOGY AND DESIGN

5.19 3.1 Chapter overview

The purpose of this study was to investigate secondary school biology teachers' knowledge bases that affect their teaching of biotechnology. These knowledge bases are essential for teachers to teach effectively and to ensure student understanding of the topic. This chapter presents and justifies the research design and methodology of the study.

This chapter outlines the research paradigm and design, providing the rationale for these choices. The selected methodology is closely related to the theoretical framework and the research questions, ensuring coherence between the study's aims and its execution. The next section discusses the sampling procedures that were used in the study. It describes how participants were selected to ensure a representative sample that can provide insightful data regarding the knowledge bases of secondary school biology teachers.

The chapter also describes research sites, giving context to where the study was conducted. This includes details about the schools and the educational environment in which the teachers operate. The chapter also describes the data generation instruments and processes, including Content Representation (CoRe), Biotechnology Test, Semi-Structured Interviews, and Classroom observations.

The chapter further discusses the methods used to analyse the collected data. It explains the analytical processes that were followed to interpret the data and draw meaningful conclusions. A discussion on research ethics follows, outlining the ethical considerations and protocols adhered to throughout the study. This ensures the study was conducted responsibly and with respect for all participants. The final section of the chapter explains the study's trustworthiness. This includes strategies that were used to ensure the reliability and validity of the findings of the study, such as triangulation, member checking, and maintaining an audit trail.

5.20 3.2 Research design

Conducting research studies is a daunting and thought-provoking experience in which the researcher must choose research paradigms and compatible research methodologies and methods to obtain accurate results (Dammak, 2011).

According to Rehman & Alharthi (2016, p.51), a paradigm is "a belief system and theoretical framework with assumptions about ontology, epistemology, methodology, and methods." A paradigm reflects the way a researcher understands the reality of the world. According to Dammak (2011), ontology and epistemology form the foundation upon which research is built, and it is the researcher's ontological and epistemological assumptions that inform the choice of methodology and methods of research.

Ontology is defined as "the nature of our beliefs about reality" (Rehman & Alharthi, as cited in Richards, 2003, p.33). These are the assumptions researchers have about how certain things exist and how they are known. Epistemology, on the other hand, is described as "the branch of philosophy that studies the nature and the process by which knowledge is acquired and validated" (Rehman & Alharthi, as cited in Gall, Gall & Borg, 2003). Patton (2002) argues that epistemological questions make a researcher debate the "possibility and desirability of generalisability, validity, subjectivity, and objectivity."

Methodology refers to the study and critical analysis of data production techniques (Rehman & Alhirthi, 2016, p.52). It guides the researcher in making decisions on the type of data required for the study and the data generation tools that will be needed. Methods, on the other hand, are defined as "specific means of collecting and analysing data such as questionnaires, and interviews" (Rehman & Alhirthi, 2016).

In conclusion, understanding the research paradigms and their components is crucial for conducting effective and meaningful research. The researcher's ontological and epistemological assumptions greatly impact the choice of methodology and methods, ultimately shaping the research design and the validity of its findings

There are many approaches to educational research. This study adopted interpretivism which states that “reality is multi-layered and complex" and it posits that “human beings are inventive and actively construct their social reality” (Dammak, 2011, p.5). Grix (2004) states that in the interpretative paradigm, the world is constructed through the interaction of individuals.

Interpretivism allows researchers to incorporate human interest into a study (Myers, 2008). It assumes that reality can only be accessed through social constructs like language, shared meanings and tools. Seen from this angle, qualitative analysis takes precedence over quantitative analysis. Interpretivism groups various perspectives together, such as social constructivism and phenomenology (Cohen, Manion & Morrison, 2007).

The interpretivist approach emphasises the importance of the researcher as a social actor, recognising distinctions among study participants. Interpretivist researchers focus primarily on meaning and may employ several approaches to reflect different aspects of a problem. Many social scientists suggest that social research should contain understandings and explanations of social phenomena that aren't always visible to the naked eye but can be interpreted by another human being, the social researcher (Matthews & Ross, 2010).

Matthews & Ross (2010) argue that interpretivism is an epistemological perspective that has evolved to prioritise people's subjective interpretations and understandings of social phenomena, as well as their own actions. This perspective can be linked to constructivism's ontological position, where the nature of a social phenomenon is found in the understanding and meanings ascribed to it by social actors.

In summary, research conducted under the interpretive paradigm has about eight characteristics which include the admission that the social world cannot be understood from the standpoint of an individual; the belief that realities are multiple and socially constructed; the acceptance that there is inevitable interaction between the researcher and his research participant; the acceptance that context is vital for knowledge; the belief that knowledge is formed by facts, which can be value-laden and requires explicit values; the need to comprehend individuals rather than universal laws; the idea that causes and consequences are mutually interrelated, as well as the belief that contextual elements must be included in any systematic quest for knowledge (Lincoln & Guba 1985; Morgan, 2007; Kivunja & Kuyini, 2017)

This study used the interpretivism paradigm to understand the experiences of teachers of biology as they teach concepts in biotechnology. Interpretivism makes it easier to understand and interpret the thoughts of participant teachers and to decipher the meaning of the phenomenon at hand (Kivunja & Kuyini, 2017). Since the social context in which people live is very critical to the researcher, interpretivism enables the researcher to capture the lives of participants which the researcher uses to understand and interpret the meaning the people attach to social issues within their context (Creswell, 2009). This implies that, in interpretivism, a researcher is solely concerned with the viewpoint of the participants of the study and not with their viewpoints. Furthermore, interpretation is a core element that defines all qualitative research (Jackson, Drummond & Camara, 2007).

3.2.1 Qualitative research approach

A qualitative research approach was deemed suitable to this study because the researcher was ultimately concerned with "the nature of phenomena which includes their quality, different manifestations, the context in which they appear, but excludes their range, frequency and place in an objectively determined chain of cause and effect, and is especially appropriate for answering questions of why something is observed, assessing complex multi-component interventions, and focusing on intervention improvement" (Busetto, Wick & Gumbinger (2020). Thus, in this study, most of the knowledge bases, such as content knowledge, pedagogical content knowledge and pedagogical knowledge, were researched using the qualitative approach (Mthethwa et al., 2014; Mphathiwa, 2015).

Merriam (2009) wrote that, "Qualitative researchers are interested in how people interpret their experiences, how they construct their worlds, what meaning they attribute to their experiences. The overall purposes of qualitative research are to achieve an understanding of how people make sense out of their lives, delineate the process (rather than the outcome or product) of meaning-making, and describe how to interpret what they experience." A qualitative research approach involves a process whereby a research problem is studied in its natural environment and not taking the participants of the study to a special place such as a laboratory (Creswell, 2007). The value of a qualitative research design is that it provides a deep understanding of phenomena compared to a quantitative research design which provides numeric data to measure differences and make predictions. Thus, the researcher also preferred the qualitative design for this study in order to gain a deeper understanding of the problem so as to explain it well (Bahari, 2012).

Thus, using the qualitative design, the researcher investigated three participant teachers' ways in which they displayed their knowledge bases. The researcher engaged each participant teacher at their school, thus allowing the researcher to observe them in their natural context. This approach also enabled the researcher to collect information from multiple sources, thus enabling the researcher to understand the meaning of the research problem through the respondents (Akinyode & Khan, 2018). This was also made possible by the many instruments which the researcher used to develop an in-depth understanding of the phenomena which could not be possible if a single case were involved.

The objectives of the this study were to: find out biology teachers' content knowledge of biotechnology; topic-specific teaching strategies secondary school biology teachers use to teaching biotechnology; students' conceptions and learning difficulties teachers experience when teaching biotechnology; how secondary school biology teachers assess students' knowledge of biotechnology concepts and how secondary school biology teachers use their knowledge of the biotechnology curriculum during planning and implementation of biotechnology lessons. The researcher felt that these objectives were consistent with those of the qualitative research approach.

3.2.2 Case study design

Case studies are in-depth investigations of a single entity or a small number of entities, which might be an individual, a family, a school, a community, or any other social unit

(Polit & Beck, 2008). In this design, researchers study the entity within a bounded system in a given context (Creswell, 2012). Case study methods explore real-life multiple, bounded cases over time through detailed, in-depth data generation involving multiple sources of information (Creswell, 2012). A case study design is commonly utilised in qualitative education research because of its adaptable and contextual character, pedagogical relevance for education research, and transparency for readers (Barrett, 2014).

The researcher adopted a case study design for this study because of its potential to best investigate the knowledge bases in the teaching of biotechnology. The researcher investigated teachers' knowledge bases in the teaching of biotechnology by interacting with the participating teachers in their respective schools and using a variety of data collection instruments. The researcher engaged a multiple case study design as several instruments were used to develop an in-depth understanding of the phenomena that a single case could provide. Each participant in the study was treated as a single case carefully ensuring that all details were taken note including ethical issues to produce reliable results. This was done before triangulation was done. Figure 3.1 helps to visualise the procedure of the study. The data generation tools are not necessarily presented in the order they were used.

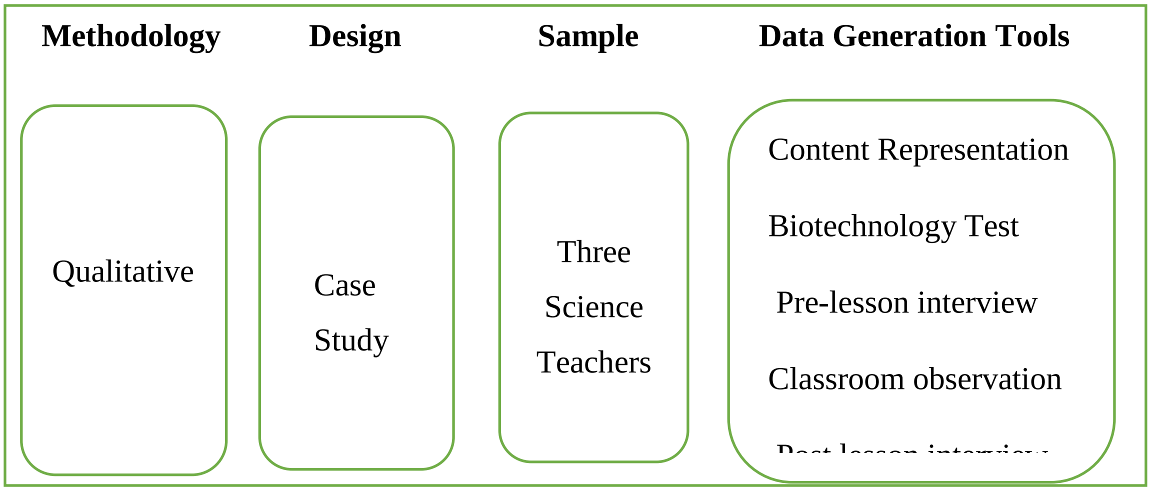


Figure 3.1: Illustration of the procedure of the study.

3.2.3 Study population

The population of study for this research was secondary school biology teachers. According to Schulman (1986), Pedagogical Content Knowledge (PCK) is a form of knowledge base which draws heavily upon an individual's knowledge of content; therefore, knowledge of content was taken as an important characteristic to be considered during the study. Since the researcher has had extensive experience as a secondary biology teacher, only secondary biology teachers were selected based on their experience as biology teachers. The study considered both specialised biology teachers (that is, those holding an education degree with biology as their teaching subject) and non-education graduate teachers who taught biology for selection in this study. The requirement for consideration for selection in the study for biology teachers without a specialised education degree was that they should have attended at least four continuous professional development (CPD) in biology under the SMASSE program. The study provided for the selection of teachers who possessed a primary school teaching certificate but were teaching biology in secondary school, provided that they attended SMASSE In-service trainings for no less than five years. The goal was to identify experienced biology teachers who were teaching form four at the time of the study because the topic under study is covered in form four. However, out of eight biology teachers who were selected, three agreed to fully take part in the study, while the remaining five agreed to take part in the pilot phase of the study.

3.2.4 Study site

The study was conducted in selected public secondary schools of Central West Education Division (CWED) which were offering biology in form four. These schools were drawn from Lilongwe rural and urban districts. The study included 3 public secondary schools, 1 from Lilongwe rural west education district and 2 secondary schools were from Lilongwe urban educational district. The schools were selected from this division and district because the location was easily accessible to the researcher and, therefore, convenient for the study.

3.2.5 Sampling procedure

Since the overall aim of the study was to investigate teachers' knowledge bases in the teaching of biotechnology as a topic in secondary school biology curriculum, the study purposely sampled biology teachers for study. Three biology teachers, one from each of the three schools selected for study, were purposely selected based on their teaching subject, teaching experience and class of teaching. For a teacher to be considered for selection, they had to be teaching biology in form 4 and had to have no less than five experience of teaching biology in secondary school. The researcher used purposive sampling of participants for this study because purposive sampling targets participants with the desired qualities, experience and knowledge that allows for collection of rich information that aids understanding of the case in its totality (Kumar, 2014).

3.2.6 Sample size

At the start of the study, eight public secondary schools were identified and visited. Four were conventional secondary schools and the other four were Community Day Secondary Schools (CDSSs). The teachers who were teaching biology in form four class were requested if they could take part in the study. Only three biology teachers accepted to fully participate in the study and they all came from CDSSs. The recruited teachers signed the consent forms after reading them carefully. These three secondary school biology teachers were sampled from the population of secondary school biology teachers of Central West Education Division, which was the location of the study. The researcher designated the three participant teachers as Joseph, John and James (pseudonyms). The other five teachers who refused to take part in the study fully accepted to take part in the pilot phase only (two females and three males).

3.2.7 The Pilot Study

This section describes the pilot study that was conducted to authenticate and assess the feasibility of the proposed methodology described in section 3.2.1

Before the study was conducted, the different instruments designed for data collection were piloted. The instruments included a biotechnology test, interview questions (introductory interview, pre-lesson, post-lesson), content representation (CoRes), and a checklist for lesson observation.

The pilot study was a small-scale study or a pre-test for particular research instruments, such as interview guides, conducted before the actual study (Aziz & Khan, 2020; Shakir & Rahman, 2022). This study helped in categorising and resolving ethical and practical issues that could endanger the main study or violate participants' human rights (Shakir & Rahman, 2022). The pilot targeted the five teachers who had turned down the request to fully participate in the study. These teachers had similar characteristics to the participant teachers of the study. Since all five teachers consented to take part in the pilot, the researcher felt that having more participants in the pilot might provide more critical eyes than having an equal or smaller number of the pilot compared to the study group. This pilot sample who taught biology and was purposively selected, and also on the basis of geographical proximity from five secondary schools within the Central West Education Division. The construction of the biotechnology test, as indicated above, was done with the assistance of the biology lecturers from Nalikule College of Education. To ensure the effectiveness of the semi-structured interview instruments, two experienced biology lecturers from Nalikule College of Education examined them based on the research questions. The instrument was piloted with five biology teachers, selected using criteria similar to those for the actual study participants. These teachers provided feedback on the clarity of the interview questions and suggested modifications to improve them. This pilot interview process proved to be an excellent training ground for conducting interviews and later assisted in transcribing and analysing the data.

Similarly, the other instruments, such as the content representation (CoRe), were critically reviewed by the same lecturers. All these data generation instruments were pre-tested using the five biology teachers.

The purpose of the pilot study was to determine the feasibility of the study; to test the reliability and validity of the different instruments and trustworthiness of respondents for data generation in the main study; to establish how appropriate, understandable and practical the instruments are; to address any problems before the main study; and to check the time required for the completion of the questionnaire. The pilot study demonstrated that the biotechnology test did not contain any confusing items, and the teachers were able to answer the questions easily. Most of the interview questions were very clear, and the teachers were able to answer without problems. Similarly, the content representations (CoRes) used in the study were aligned with the biotechnology curriculum.

The findings from this pilot study informed the reformulation of the objectives of the study, revision of ambiguous questions, and planning for the main research study.

5.21 3.3 Data collection methods and tools

Data for this study were collected using Content Representations (CoRe), biotechnology test, interviews, classroom observations and document analysis. This type of generating data is what Creswell (2011) calls a "multiple sources of information". This was done to enable the researcher create a rich description of different knowledge bases that were identified in the study. These knowledge bases included content knowledge, pedagogical content knowledge, knowledge of assessment, knowledge of curriculum and other components of PCK.

Each data collection tool was designed to address one or more research questions about teachers' knowledge bases in the teaching of biotechnology as a topic, with special attention to knowledge bases as they are reflected in the areas of planning, teaching and reflecting. According to Wilson, Stuhlsatz, Hvidsten, & Gardners (2018), PCK as teachers' professional knowledge is visible in the work done by the teacher and involves planning, teaching and reflecting. Table 3.2 shows the data generation tools that were used in this study and the knowledge bases that were investigated in the study.

Table 3.2: List of knowledge bases against the data generation instruments

Type of knowledge	**Data generation instrument used**
Content knowledge	Content Representation, Biotechnology test, interviews, classroom observations and document analysis
Pedagogical knowledge	Content Representation, interviews, classroom observations and document analysis
Knowledge of curriculum	Content Representation, interviews, classroom observations and document analysis
Knowledge of learners and their characteristics	Content Representation, interviews and classroom observations
Knowledge of self	Interviews and classroom observations
Knowledge of educational purposes	Interviews, classroom observations and document analysis
Knowledge of the educational context	Interviews, classroom observations, document analysis
Topic-specific Pedagogical content knowledge	Content representation, Biotechnology test, interviews, classroom observations and document analysis

3.3.1 Content representations

The study employed Content Representations (CoRes) as one of the key instruments to assess the Pedagogical Content Knowledge (PCK) of biology teachers, focusing on the teaching of biotechnology. Content Representation (CoRe) refers to the teaching of a specific topic to a specific group of students (Mulhall, 2003). This approach, developed by Loughran et al (2012), provides a comprehensive method for understanding how teachers plan, teach, and rationalise their instructional strategies for a specific topic and student group (Berry, and Mulhall, 2012). To quote Loughran, Content Representation represents "a generalisable form of the participating teachers' pedagogical content knowledge as it links the how, why, and what of the content to be taught with what they agree to be important in shaping students' learning and teachers' teaching". (Loughran et al, 2012. p17).

The researcher introduced the CoRe (Content Representation) template to each participating teacher and discussed it in detail. Using the example of a CoRe on the topic of the circulatory system (Loughran et al., 2008), the researcher explained how to use the template. The participants were then individually guided to focus on biotechnology, the topic for which they had to develop a CoRe.

While Loughran et al. (2012) used CoRe for interviews and classroom observations, in this study, it was initially an individual assignment where teachers identified big ideas and responded to eight prompts related to teaching biotechnology. Given the challenges in identifying Big Ideas (as noted by Loughran et al., 2012), a template with predefined Big Ideas was later provided to the teachers. They were given two weeks to complete their CoRes, after which a test was conducted before they taught the topic in their schools. The template was provided to ensure that all participants use the same big ideas (Mphathiwa, 2015). This was the recommended procedure so that all participants are using the same Bid Ideas.

Garritz and Velazquez (2009) indicated that secondary school biotechnology teachers' PCK (Pedagogical Content Knowledge) can be documented using CoRes. This approach helps in identifying, classifying, distinguishing, and discussing their pedagogical reasoning. Consequently, this study utilised CoRes not only to investigate the teachers' pedagogical reasoning but also to examine their content knowledge, pedagogical knowledge, and other relevant knowledge bases.

The standard content representation (CoRe), which was used to identify the teacher's knowledge bases, was developed by the researcher, assisted by the lecturers from Nalikule Teachers' College, and edited by an expert from the University of Malawi. The original content representation (CoRe) was adopted from Garritz and Velazquez (2009) and modified to address the Malawian biotechnology curriculum. This CoRe was piloted using the five pilot teachers who commented in the areas which were not clear to them after they were also oriented on how they are developed and used.

3.3.2 Biotechnology test

The researcher developed a test based on the MSCE biology curriculum content to investigate the biology teachers' content knowledge on the biotechnology topic. One issue raised regarding the use of tests to assess teachers' content knowledge is the suitability of the item format, such as the use of closed-item questions like multiple-choice or open-ended questions (Schmelzing, Van Driel, Jüttner, Brandenbusch, Sandmann, & Neuhaus, 2013). According to Schmelzing et al. (2013), closed-item structures can complicate the formulation and assessment of accurate responses and may lead to distractions. In contrast, open-ended questions provide an opportunity to assess the unique content knowledge teachers have on a specific topic (Schmelzing et al., 2013). Therefore, the test developed for this study consisted of open-ended questions. The test comprised nine questions with varying levels of difficulty, from recall to comprehension questions (see Appendix G). This test structure was designed to comprehensively assess the teachers' content knowledge and their understanding of the biotechnology topic from multiple angles, including factual recall, conceptual understanding, and the ability to articulate and apply their knowledge.

The questions were developed based on the success criteria provided in the biology MSCE curriculum (Table 3.3). The biotechnology test was administered to the biology teachers in their respective schools, and they were given 45 minutes to complete it. The teachers were assured that their identities would be kept confidential, with pseudonyms being used in the study. The teachers' answers were coded as right, partial or wrong. An answer was coded as right if it was acceptable and scientifically accurate, while answers that were incorrect or lacked essential scientific information were coded as partial or wrong depending on the gravity of the answer provided. This coding or scoring was used because all the expected answers were scientifically collect and there were very few partial answers to the questions where a participant could obtain half mark.

Table 3.3: List of success criteria for the teaching of biotechnology

Students must be able to

1. *give examples of plant and animal breeding*
2. *describe the applications of biotechnology*
3. *describe the process of genetic engineering*
4. *explain how insulin is produced*
5. *discuss other applications of genetic engineering*
6. *discuss the ethical implications of the use of biotechnology*

3.3.3 Interviews

According to Matthews and Ross (2010), an interview is a data gathering approach that allows the interviewer to elicit facts, sentiments, and opinions from the interviewee through questions and interactive discourse. Interviews can be conducted face-to-face, over the phone, or via the Internet. Ary, Jacobs, and Sorensen (2010) state that there are many types of research interviews, with the three most commonly used being unstructured, structured, and semi-structured interviews.

Unstructured interviews are comparable to ordinary conversations, involving a two-way dialogue where the interviewer and the interviewee communicate one-on-one with little standardization (Ary, Jacobs & Sorensen, 2010). Structured interviews rely heavily on the interviewer's preparation of a schedule that outlines the specific order of questions (Creswell, 2009; Ary, Jacobs & Sorensen, 2010). For each interview, the interviewer uses the same set of questions and asks them in exactly the same way, using the same phrases and probes (Matthews & Ross, 2010).

Semi-structured interviews, like structured interviews, use a prepared schedule with specified questions but differ in that the questions are not asked in any particular sequence; the order is dictated by the responses received from the participant (Creswell, 2009). The interviewer may introduce themes or questions in various ways or sequences depending on the interview, allowing the participant to answer or discuss the topic in their own words (Matthews & Ross, 2010).

The semi-structured interview was used in this study to understand what teachers know and to ask them to provide reasons where necessary. Interviews are a major source of qualitative data (Willig, 2013) and were used to explore teachers' ideas related to teaching and student assessment, aspects that cannot be observed directly. Creswell (2009) describes interviews as a type of conversation with the specific aim of obtaining information using the spoken word.

The first interview was conducted before classroom observations and aimed to gather information about participants' teaching backgrounds, orientations to science teaching, and knowledge of teaching biotechnology. Turner-Bisset (1999) argued that knowledge of the educational context is very important because it affects teachers' performance. This context includes factors such as the type and size of the school, the catchment area, class size, the extent and quality of support teachers receive, the quality of relationships within the school, and the expectations and attitudes of the school's management. Therefore, participants were asked about the number and types of schools they had taught at before joining their current schools, the working relationships within their current school, the support they received from management, and other related issues.

The second and third interviews were pre-lesson and post-lesson interviews, respectively. All these interviews were semi-structured. Semi-structured interviews were chosen because they allow flexibility: the interviewer uses a prepared guide with specific questions organised by topics but does not necessarily ask them in a specific order. The actual order is determined by the responses received from the interviewee (Bailey, 2007).

3.3.3.1 Pre-lesson interviews

The pre-lesson interviews were semi-structured and conducted before each biotechnology lesson. These interviews aimed to understand how teachers were planning their biotechnology lessons (see appendix B) and to assess their biotechnology content knowledge, instructional strategies, and understanding of students' conceptions and learning difficulties. Each interview lasted an average of 15 minutes. According to Zaare (2013), pre-lesson interviews help to alleviate anxiety and provide the researcher with insights into how the lesson will be taught and what the teacher intends to teach that day.

During the main study, the pre-lesson interviews were voice recorded with the permission of the participants and later transcribed for analysis.

3.3.3.2 Post-lesson interviews

The researcher conducted one semi-structured interview with each participant after every lesson. Each post-lesson interview lasted approximately 30 minutes. The aim of the interview was to find out the participants' self-assessment of their lessons. Thus, the post-lesson interview served as the teacher's own reflection of what happened during the lesson (see appendix C).

Post-lesson interviews provided additional insights into the teachers' perspectives on teaching biotechnology and helped enrich the data gathered through lesson observations. These interviews aimed to identify any misconceptions students had during the lesson and to understand how the teacher assessed the content of the lesson. During the post-lesson interviews, teachers had the opportunity to clarify points made during the lessons. The interview was recorded and transcribed.

This interview data was analysed to provide insight into the teachers' knowledge of biotechnology content, teaching strategies, areas where they encountered learning difficulties, and their knowledge of assessment, among other knowledge bases.

3.3.4 Classroom observations

Observation is a method of generating qualitative data that involves the researcher immersing themselves in a setting of the research with a view to experience and observe first hand a variety of issues, including social action, behaviour, interactions, and relationships (Creswell, 2012). Observation has both advantages and disadvantages. Its advantages include are that it records information as it occurs in a setting and that it studies the real behaviour of the participants (Creswell, 2012). Some of its disadvantages include difficulty in developing rapport with individuals and limited observation to easily accessible sites (Creswell, 2012).

There are three main types of observation: participant observation, non-participant observation, and indirect observation. In participant observation, researchers engage in the activities at the study site while recording the necessary information. Non-participant observation involves the researcher visiting and recording notes without participating in the activities of the participants. Indirect observation relies on observations made by others, as well as on documents or recordings (Ciesielska, Boström, & Öhlander, 2018).

This research study used non-participant observation, where the researcher sits on the periphery, such as at the back of a classroom, to observe and record the phenomena under study (Creswell, 2012). The researcher maintains different positions at the site to remain neutral and minimise interference, allowing the teacher and students to almost forget about their presence as the lesson progresses. This method requires less access to the research site than participant observation (Ciesielska et al., 2018) and has many advantages that enhance the reliability and validity of the data generated. When participants are in their natural environment, the study guarantees validity, may trigger original thoughts and research questions, allows researchers to obtain real data, and avoids potential issues with self-reported data. It also opens the researchers' eyes to alternatives they may not have previously considered (Creswell, 2012).

Teachers were observed in the classroom while teaching the biotechnology topic. they were observed teaching the same success criteria (objectives). Classroom observation provided crucial information about teachers’ content knowledge, teaching strategies, pedagogical application, and other forms of knowledge bases, most of which are components of PCK (Pedagogical Content Knowledge). The observation focused on the biotechnology content being taught and how teachers interacted with their students. It also captured the teachers' prior knowledge of their students’ conceptions and the strategies they used to identify students’ conceptions and misconceptions. Students’ questions, answers, and the feedback provided by the teachers were also noted.

All lessons observed were video recorded with the consent of the participants. Three lessons per teacher were observed and video recorded to reach saturation. An observation checklist was used as a supplement during the lesson observation, considering that the lessons were recorded (see Appendix E).

3.3.5 Document analysis

In qualitative research, documents are a valuable source of data. According to Bryman (2008), documents are created in specific forms for consumption by particular groups of people, necessitating careful consideration in research. These documents can be categorised as primary or secondary. Primary documents are authored by research participants themselves, such as lesson plans and notes, while secondary documents are authored by others and used as reference material, such as textbooks (Willig, 2013).

In this study, various authentic documents were identified and utilised to explore the relationship between teacher understanding, pedagogical choices, and biotechnology content. These documents included Senior Secondary School Biology Syllabus, which provided official guidelines and expectations for teaching biotechnology, Recommended Senior Biology Textbooks, which are used as secondary sources to understand the content and context of biotechnology, Participants' Lesson Plans and Schemes of Work, which offered insights into how teachers planned and structured their lessons on biotechnology. The researcher also used CoRe Templates, which were used by teachers to organise and plan their teaching of biotechnology, and Samples of Students' Exercise Books, which provided evidence of what students were learning and how concepts were being conveyed.

These documents were analysed and interpreted to establish teachers' understanding of biotechnology and to gain insights into current practices and issues in teaching this subject. Triangulation of data from multiple sources like these documents helps ensure a comprehensive understanding and interpretation of the data collected in the study.

5.22 3.4 Data analysis

In this qualitative study, data analysis was grounded in the adapted consensus model's knowledge bases and the guiding research questions. This includes the coding, thematic analysis and the data organisation. Data analysis is conducted in order to draw inferences from the raw data to be able to generate broad findings for the study and answers for the questions which guided the study (Augustine, 2014). Data analysis was guided by an interpretivist approach, which focuses on providing detailed descriptions and understanding the context and meanings inherent in the data (Cohen, Manion & Morrison, 2007). The goal of data analysis in this context was to describe, examine, assess, and explain the content and features of the data generated by the research (Matthews & Ross, 2010). Data analysis in qualitative research is defined as a process which involves organising, disassembling, segmenting, and reassembling the data generated (Schreier, 2012).

Thematic analysis was employed to scrutinise and organise the data in response to the research questions. The data sources included the biotechnology test, transcribed lessons observed, semi-structured interviews, and Content Representation templates (CoRes). The analysis specifically focused on investigating various knowledge bases. These included Content Knowledge (CK): Understanding of biotechnology concepts and principles, Curriculum Knowledge (CRK), Assessment Knowledge (AK), and Pedagogical Content Knowledge (PCK).

The analysis also explored elements of Topic-specific PCK, such as content representation, curriculum saliency, students' prior knowledge integration, and teaching strategies aligned with success criteria in biotechnology education. Data relevant to pedagogical knowledge was extracted from transcribed lessons, while other aspects (CK, SK, CRK, AK, PCK) were directly linked to specific research questions and instruments used.

The data analysis process started with a single-case analysis, where each participant's data was analysed separately from content knowledge to knowledge of biotechnology. However, topic-specific pedagogical content knowledge (TSPCK) was analysed separately because the comparison was done using a table which could not be split. This was followed by cross-case analysis, comparing findings across all participants. This approach allowed for a comprehensive exploration of the research questions using data collected from Form Four biology teachers.

Data analysis began with the transcription of the semi-structured interviews immediately after the participants signed the consent forms. The first interview was conducted to collect general information such as their qualifications, teaching experience, the class sizes, their catchment areas, among other issues. This was followed by interviews, which were conducted before and following the lesson observation cycle for each participant. The researcher personally transcribed all interviews to gain a greater understanding of the participants and the data. All transcribed interviews were carefully reviewed for accuracy. Similarly, all six video clips for the lessons were transcribed and viewed many times to make sure that important aspects of participants' practice were not missed.

3.4.1 Development of Codes

When developing codes for teacher knowledge bases, the researcher drew upon the work of Newsome (2015), who developed codes within teacher professional Knowledge bases (TPKB) and the specific topic pedagogical content knowledge (TSPCK). The researcher used the adapted consensus model and drew upon codes from the model to develop codes for data analysis within the following dimensions of TPKB and TSPCK which include: (1) knowledge of content, (2) knowledge of representations and instructional strategies, (3) knowledge of students' understanding of science, (4) knowledge of assessment, and (5) knowledge of curriculum.

3.4.2 Case Profiles

The creation of the case profiles was a step-by-step process. Firstly, the data generated from multiple sources was combined for each case except for topic-specific pedagogical content knowledge (TSPCK). Secondly, using the codes described in the previous section, the data were analysed, and this data constituted a case profile for each teacher participant, beginning with their content knowledge, followed by the analysis of one of the components of TSPCK, teaching strategies identified by the adapted consensus model. Knowledge of students, assessment and biotechnology curriculum followed the teaching strategies. The researcher used either verbatim data excerpts or descriptions to tell the story of each participant and to support the interpretation of the participant teacher's knowledge bases and their topic-specific PCK for teaching biotechnology. The researcher developed a brief description for each participant teacher as an introduction to the case profile.

The case-by-case analysis allowed the researcher to develop specific assertions about each participant in terms of their knowledge bases, such as content knowledge, knowledge of students, assessment, curriculum and components of topic-specific pedagogical content knowledge of teaching biotechnology, such as teaching strategies, content representations, curriculum saliency, among other components.

3.4.3 Cross-case Comparison

A cross-case comparison of study participants was conducted to make comparisons between the individual case profiles. Unique cases are well understood by comparative analysis (Patton, 2002). The cross-case comparison was also used to identify differences and similarities among the participants in terms of their knowledge bases, their level of knowledge and topic-specific PCK of the study participants.

In addressing the first research question, "How much content knowledge of the biotechnology topic do biology teachers have?", multiple instruments were employed to gather and analyse data. The first instrument was a biotechnology test, which consisted of nine questions aligned with the six success criteria from the Form Four biology curriculum on biotechnology. The answers were analysed by comparing them with the answers found in the recommended core textbooks used by the schools. This process ensured that the test was aligned with the curriculum and that the content was accurate and relevant for assessing the teachers' knowledge of biotechnology. Teachers' responses were coded as correct (right), incorrect (wrong) or partial based on scientific reasoning. This instrument aimed to assess teachers' content knowledge (CK) in biotechnology.

The second instrument was Content Representation (CoRe). The teachers independently completed their own CoRe templates for teaching biotechnology using the provided Big Ideas. These CoRes were analysed to explore teachers' pedagogical content knowledge (PCK) and other knowledge bases, including content knowledge by comparing what the participants had prepared to a standardised CoRe prepared by the researcher (appendix P).

Thirdly the researcher used the recorded videos for all the lessons which were observed. A classroom Lesson Observation was used as a supplementary instrument in guiding the researcher different sections of a lesson. These observations provided insights into how teachers applied their content knowledge in instructional settings. The observation data for the three teachers were transcribed and analysed to investigate the knowledge bases. Field notes described the classroom setting, students, teachers' writings on the chalkboard, teaching strategies, and how the lessons were handled. The video recordings were fully transcribed, capturing every action and all verbal interactions between teachers and students. This type of data is important because it provides a detailed account of what happened during the biotechnology lessons (Aydemir, 2014). The observation data, along with the field notes, were analysed to investigate the biology teachers' knowledge bases in the teaching of biotechnology.

The fourth instrument which was used is interviews. The semi-structured interviews were recorded, transcribed, and coded to identify components of PCK and other knowledge bases. Open coding and thematic analysis were used to analyse the content of the semi-structured interviews.

Open coding, a method developed by Glaser and Strauss (1967), involves breaking down data into conceptual units, conceptualising them, and reconstructing them into new categories. Open codes were broad descriptions of events or statements made by participants. Thematic analysis is a multi-stage procedure which involves developing themes from the data through a process of open coding and then moving into selective coding. The goal was to derive categories and themes that addressed the main research question regarding teachers' understanding of biotechnology content knowledge.

To investigate the second research question, "What topic-specific teaching strategies do biology teachers use in the teaching of biotechnology concepts?" Several instruments and methods were employed. These included transcribed lessons. The transcribed lessons were used in identifying teaching strategies used by teachers during biotechnology lessons. The CoRes were compared to a standard CoRe developed by three experienced biology lecturers (See appendix P). The comparison helped identify the teaching strategies planned or suggested by the teachers for their lessons. Coding analysis was employed to assess the alignment of these strategies with recommended pedagogical approaches and curriculum standards.

Another instrument which was used is document analysis. Under this, schemes of work, lesson plans, student textbooks, and the Form Four biology curriculum were analysed to identify any documented teaching strategies used in the biotechnology lessons. This document analysis provided supplementary insights into the intended instructional methods and strategies prescribed by the curriculum. The final instrument which was used to gather data on this question is set of transcribed semi-structured interviews. These interviews provided qualitative data on the rationale behind their instructional choices, as well as insights into their pedagogical reasoning and decision-making processes.

The combined use of these instruments (classroom observation, CoRe analysis, document analysis, and interviews) enabled a thorough exploration of the topic-specific teaching strategies employed by biology teachers in teaching biotechnology concepts. The triangulation of data from multiple sources ensured a comprehensive understanding of how teachers approached instructional planning and delivery in biotechnology education, aligned with both curriculum guidelines and their own pedagogical insights. This approach facilitated a nuanced analysis of teaching practices and strategies within the specific context of biotechnology education.

Data for the third research question, “What knowledge of students’ conceptions and learning difficulties do biology teachers have about biotechnology?", was gathered through content representation, classroom lesson observation and interviews. Under content representation, the researcher compared teachers’ CoRes with standard CoRe to assess the teachers’ understanding of students' conceptions and potential learning difficulties in biotechnology. Thereafter, the researcher employed coding analysis to compare and identify elements related to student knowledge and learning difficulties as reflected in the CoRes.

The researcher conducted classroom lesson observations which were recorded. The data that was collected from the observations was transcribed and analysed to uncover insights into how teachers addressed student conceptions and learning difficulties during instruction. The final instrument used to gather data on the third research question was interviews. The researcher conducted semi-structured interviews with participant teachers both before and after lessons. The data generated from the interviews was coded and analysed thematically. The analysis focused on teachers' knowledge of students' prior knowledge, misconceptions, and learning difficulties in biotechnology.

The researcher analysed teachers’ knowledge of students in relation to biotechnology was analysed in two main ways. Firstly, it was through analysing students’ prior knowledge on biotechnology, with special focus on teachers' understanding of students' prerequisite knowledge and skills necessary to grasp biotechnology concepts. The second approach was based on Topic-Specific Pedagogical Content Knowledge (TSPCK) which analysed teachers' awareness of students' specific misunderstandings or difficulties related to biotechnology concepts.

Data for the fourth research question, "How do these biology teachers assess students’ understanding of biotechnology concepts?", was generated using lesson observations, semi-structured interviews and document analysis. The lessons were recorded and transcribed and thereafter open coded to identify and categorise methods and strategies used by teachers to assess students' understanding of biotechnology concepts. Semi-structured interviews were also conducted with participant teachers to provide additional insights into their assessment practices. The interviews were recorded, transcribed and analysed thematically. Thematic analysis of data was conducted to explore teachers' perspectives on assessment strategies and their effectiveness. Document analysis was the final instrument that was used to gather data on this research question. The researcher analysed schemes of work, lesson plans, and student notebooks. Document analysis was used to complement findings from other instruments, focusing on how assessment strategies recommended by the curriculum (e.g., group assessment, individual appraisals, peer appraisals, oral and written exercises) were implemented.

To address the fifth research question, "How do biology teachers use the biotechnology curriculum knowledge when planning and implementing biotechnology lessons?", multiple instruments and methods were employed. The first instrument was lesson observation. Observations were conducted to examine how teachers implemented the success criteria outlined in the Form Four biology curriculum for biotechnology. The second instrument was document analysis which was used to assess teachers' knowledge of curriculum content related to biotechnology. The third instrument the researcher used to generate data on this question is interviews. Semi-structured interviews were conducted to gather teachers' perspectives on their use and interpretation of the biotechnology curriculum.

Thereafter, the researcher used thematic analysis to identify instances where teachers aligned their teaching practices with the curriculum's specified success criteria. Also, using document analysis, the researcher reviewed schemes of work, lesson plans and student note books. Schemes of work were reviewed to understand how biotechnology lessons were planned over time whereas lesson plans were analysed to see how teachers structured their instructional activities in accordance with curriculum guidelines. Student notebooks and textbooks were examined to assess how curriculum content was presented and reinforced to students.

Table 3.3: Summary of Data Analysis Process

Research Questions	Data Source	Data Analysis and Generation Technique
How much content knowledge of the biotechnology topic do biology teachers have?	Biotechnology Test Observation of lessons Interviews, Observation of lessons, CoRes	Analysis of teachers' answers to the Biotechnology test. The content of observations and semi-structured interviews was analysed using open coding and thematic analysis. The CoRes were compared to a standard CoRe
What topic-specific teaching strategies do biology teachers use in teaching biotechnology concepts?	Observation of lessons Interviews CoRes, Lesson plans and students' notebooks	The content of observations and semi-structured interviews was analysed using open coding and thematic analysis. The CoRes were compared to a standard CoRe; Document analysis of lesson plans and students' notebooks
What knowledge of students' conceptions and learning difficulties do biology teachers have about biotechnology?	Interviews, CoRes, Observation of lessons	The content of the semi-structured interviews was analysed using open coding and a thematic system. The CoRes were compared to a standard CoRe. Transcription of videos from lesson observation, followed by thematic analysis.
How do these biology teachers assess students' understanding of	Semi-structured interviews, Observation of lessons, Schemes of work, Lesson plans and Student notebooks	Semi-structured interviews' content was analysed by open coding and thematic system; Transcription of videos from lesson observations, followed by thematic analysis. Document analysis of documents such as schemes of work

biotechnology concepts?		
How do biology teachers use the biotechnology curriculum knowledge when planning and implementing biotechnology lessons?	Semi-structured interviews, Schemes of work, lesson plans, student notebooks, Textbooks being used Lesson observations	Open coding and thematic system; Knowledge of curriculum was analysed by a document analysis of schemes of work, lesson plans, student notebooks and textbooks; Transcription of videos from lesson observation followed by thematic analysis

3.4.4 Analysis of biotechnology test

The development and implementation of the biotechnology test followed a structured process to ensure its validity and alignment with the MSCE syllabus and recommended textbooks. The test was administered to the three participating biology teachers. The test papers were analysed based on the marking key. The total scores for each teacher were compared in terms of overall marks and performance per question.

3.4.5 Analysis of classroom observations, interviews and textbooks

Content analysis is defined as "a compiled scientific approach where written materials are methodically evaluated, then classified based on particular criteria to make information obtained accessible and, lastly, to give a platform for future research" (Wallen & Hyun, 2012; Dincer, 2017). Content analysis also involves reduction of qualitative data and making sense of it with the goal to find basic consistencies and meanings, which are sometimes referred to as patterns or themes (Egmir, Erdem & Kocyihit, 2017).

Transcribed Observed Lessons were analysed using coding to extract information about teaching strategies, content coverage, and interactions between teachers and students during biotechnology lessons. Transcribed Interviews provided insights into teachers' perspectives, knowledge of content, teaching strategies, areas where they encountered learning difficulties and assessments related to biotechnology among other knowledge bases. On the other hand, textbook chapters on biotechnology from recommended MSCE textbooks were studied to understand how the content was presented, its alignment with curriculum objectives, and its relevance to the broader context of biotechnology education.

3.4.6 Analysis of content representations

The CoRes were then used in the analysis of the PCK of each participant on biotechnology. Different kinds of knowledge were assessed, including students' prior knowledge, content representation, difficulties in teaching the topic, teaching strategies, and curricular saliency. Participants were scored based on a rubric adapted from Mavhunga and Rollnick (2011) and Mphathiwa (2015). The adapted rubric has five components of TSPCK. Each of the eight questions or prompts on the CoRe was rated on a scale of 1 to 4, where 1 represented limited, 2 represented basic, 3 represented developing, and 4 represented exemplary (refer to scoring guidelines in Appendix Q).

The rubric was validated by two biology lecturers. The lecturers scored two CoRes from a pilot study independently. They were briefed on developing CoRes and on how to use the rubric. Both the researcher and the lecturers scored the circulatory system CoRe by

Loughran et al. (2012) to align the scoring methods. The average score after this exercise was 79%. Scores for each teacher were calculated by summing the scores for the TSPCK elements. Comparisons were made between the TSPCK elements for the three participants.

5.23 3.5 Trustworthiness

This section discusses how the study's trustworthiness was established. Trustworthiness is a very critical aspect of any research because it is one way a researcher can persuade other researchers that their research findings are worthy of attention (Lincoln & Guba, 1985). There should be assurance in validity and transferability of study findings where ethical considerations of the researcher are very important to ensure credibility, confirmability and transferability in qualitative studies (Merriam, 1998). Lincoln & Guba (1985) came up with a concept of trustworthiness by introducing the criteria of credibility, transferability, dependability and confirmability, which were parallel to the conventional quantitative research criteria of validity and reliability.

Credibility

Stahl & King (2020, p. 26) state that credibility asks the question that "How congruent are the findings with reality?" Guba and Lincoln (1989) argued that the credibility of any study is determined when a fellow researcher is confronted with an experience he/she could recognise. In this research study, credibility was established through the piloting of the four different tools in the study, peer validation where two colleagues had access to the study and shared their vies and ideas to the findings and the use of more than one data generation tool or method or triangulation (That is, biotechnology test, interviews, lesson observations and content representa). According to Merriam 1998, this involved using "multiple sources of data or multiple methods, to confirm the results. Triangulation is the use of several sources of information or procedures from the field repeatedly to establish identifiable patterns (Stahl & King, 2020). These could either be methodological triangulation or data triangulation. Peer validation provides an external check on the research process, which increases credibility (Nowell, Norris, White, & Moules, 2017).

Transferability

Transferability refers to the generalisability of a study or to what extent the findings of one study could be applied to another study (Nowell et al, 2017; Merriam, 1998). In qualitative research, the findings are specific to a small number of particular environments and people, as a result, it is impossible to show that the findings and conclusions apply to other situations and populations (Shenton, 2004). Therefore, this study was a case study, hence, transferability is limited. Mphathiwa (2015) argues that a case study cannot offer transferability unless the reader recognises the applicability of the findings to his/her situation. However, Lincoln & Guba (1985) also argued that it is the responsibility of the researcher to ensure that enough related information about the location of the study is provided so that the reader can make such a transfer. Therefore, this study used purposive sampling provided detailed background data on the study to establish the context of the study and a comprehensive description of the literature on the study so that the reader can easily make a comparison.

Dependability

Nowell et al (2017) claim that to achieve dependability, a researcher should ensure that the research process is consistent, traceable and well documented. This means that different researchers using the same methods in the same setting and context would get similar results if the study is repeated (Mphathiwa, 2015). Dependability is enhanced through good recording of the lessons observed, interviews conducted and well documented field notes. Therefore, dependability in this study was achieved through piloting of the different data generation tools before they were used, and the data was transcribed before analysis to reduce bias and improve accuracy. The role of the supervisors was very critical because they evaluated the ideas, activities and reports.

Confirmability

Denscombe (2007) defines confirmability as the degree to which research findings are created by the participants and not by the researcher's interest or bias. Confirmability is recognised when credibility, dependability and transferability are accomplished (Guba & Lincoln, 1989). Looking at the techniques used in the analysis and the quality of interpretation of the results, an independent assessment of the study could be made to confirm the findings of the study. For example, appendices J, K, and L show the original CoRes developed by the participants and appendices M, N and O show the CoRes which were compiled by the researcher using data obtained through the interviews. Appendices R and S show a sample transcribed lesson and a sample transcribed interview, respectively. Triangulation was used as the main strategy to achieve confirmability.

5.24 3.6 Ethical considerations

The researcher sought permission for the study from the University of Malawi through the School of Education's Department of Curriculum and Teaching Studies (refer to Appendix H). The researcher also obtained permission to conduct the study in the schools involved from the Ministry of Education, Science and Technology (refer to Appendix I) and from the heads of the secondary schools which were involved in the study.

Participants who were recruited in the study were informed about the study before engaging them in the study, so they could give their consent with full information about the purposes of the study and its associated activities. The information the study collected was used only for this study and, therefore, was not disclosed to third parties. Participants were informed during recruitment that they could withdraw from the study at any time or stage of the research. Also, to promote the health and safety of the participants, the researcher strictly adhered to all Covid-19 preventive measures as stipulated in the Covid-19 guidelines.

5.25 3.7 Limitations of the study

This study is a qualitative study and may make generalisation of the findings limited as very few participants were used. Also, the study recruited three secondary school biology teachers only from the vast population of secondary school biology teachers in the Central West Education Division (CWED). The biology teachers who were recruited in this study taught learners whose unique characteristics differed from those of students in secondary schools with a status higher than that of CDSSs (O'Brien, 2017). The researcher analysed two out of seven lessons each participant teacher had prepared which might have affected the findings of the study. The knowledge bases that were investigated were affected by a number of factors related to teaching experience, training on content knowledge of biotechnology topic and teachers' beliefs among others. However, this study used purposive sampling method which is suitable for qualitative research

5.26 3.8 Summary of the chapter

This chapter detailed the research design and methodology employed in the study. The chosen research design enabled an investigation into the knowledge bases biology teachers use to teach biotechnology in Malawian secondary schools. Teachers who voluntarily agreed to participate were identified for the study. The chapter also described various data generation instruments and explained how the data were analysed to address both the main research question and the specific research questions.

The next chapter presents the findings and discussion of the entire study. It begins with an introduction, followed by the results in Section 4.1. This is followed by the discussion in Section 4.2, and the chapter concludes with a summary.

CHAPTER FOUR

PRESENTATION AND DISCUSSION OF FINDINGS

5.1 Chapter overview

This chapter presents and discusses the study's findings in relation to each specific research question. The purpose of this study was to investigate how secondary school biology teachers use their knowledge bases in teaching concepts in biotechnology. Knowledge bases include all cognitive skills needed to create effective teaching and learning settings (Guerriero, 2012). The specific objectives of the study were to find out (1) biology teachers' content knowledge of biotechnology, (2) topic-specific teaching strategies secondary school biology teachers use to teaching biotechnology, (3) students' conceptions and learning difficulties teachers experience when teaching biotechnology, (4) how secondary school biology teachers assess students' knowledge of biotechnology concepts and (5) how secondary school biology teachers use their knowledge of the biotechnology curriculum during planning and implementation of biotechnology lessons. The researcher gathered data through interviews, Content Representation (CoRe), biotechnology tests and lesson observations.

To investigate the teachers' experiences in teaching biotechnology concepts, the study employed an interpretivist paradigm and a qualitative research approach, utilising a case study design. The study chose interpretivism for its potential to enable a researcher to understand the subjective experiences and interpretations of the participant teachers as they taught biotechnology. Interpretation is a key component of qualitative research (Barret, 2014). Thus, the researcher assigned interpretation to the analysis of the generated data to identify the knowledge bases the teachers used as well as how the knowledge bases were used.

The qualitative design was chosen for its adaptability, contextual relevance in education research, and transparency for readers (Creswell, 2012). It was also chosen because of its potential to allow for a deeper understanding of the participants’ perspectives and experiences. A case study design was preferred for this qualitative research due to its ability to provide an in-depth investigation of a small number of participants, in this case, three individual teachers.

5.2 Presentation of findings

The study sought to understand how biology teachers use their knowledge bases in teaching biotechnology. The study focused on the knowledge bases such as content knowledge of biotechnology, topic-specific teaching methods for teaching biotechnology, teacher’s understanding of students’ learning challenges and students’ misconceptions, teachers’ methods for evaluating their students’ knowledge and understanding of biotechnology, and teachers’ use of the biotechnology curriculum knowledge during lesson planning and implementation.

This section provides case profiles for each of the three study participants. The aim of the cases is to provide an in-depth profile study participants’ knowledge bases for biotechnology. Each of the case profiles is organised in a manner reflective of the adapted consensus model. The profiles are based on the multiple data generation sources used, and the cases are based on the researcher’s interpretation of the findings from the different instruments used.

Each participant's case profile has the following sections: findings on content knowledge based on biotechnology test performance, semi-structured interviews and from transcribed lessons. This is followed by teaching strategies based on transcribed lessons and the content representation (CoRe). This is followed by the participant's knowledge of students and awareness of learning difficulties. The next section has findings on knowledge of assessment and then knowledge of the biotechnology curriculum. The findings conclude with those on topic-specific pedagogical content knowledge (TSPCK). The next section is a presentation of a cross-case analysis of the three case profiles based on the description of the major themes observed across the cases, and is organised according to the research questions which guided this research study.

Joseph's Case Profile

Background and context

At the time of this study, Joseph's experience as a biology teacher spanned 15 years. He possesses a Bachelor of Science education degree with biology as his major subject and chemistry as his minor subject. He had taught for 15 consecutive years at the same school where the study was conducted. In addition to his 15 years' experience as a biology teacher, Joseph also boasts of his experience as a SMASSE Division Trainer of chemistry teachers in CWED. In addition, Joseph is also a part-time chemistry lecturer at the Lilongwe University of Agriculture and Natural Resources (LUANAR), where, at the time of this study, he had taught for five years. The total student population of the school at the time of the study was 300, but Joseph's form 4 biology students were 20 (11 males and 9 females). The researcher observed Joseph teaching form 4 because the biology topic of interest for this study, biotechnology, is taught in the third term of form 4. He clearly stated that he has been given all the support by the school administration. When he requests teaching and learning materials

Findings on content knowledge

The first research question for this study sought to determine the content knowledge of biology teachers on biotechnology. Data for this question was generated through a biotechnology test that was administered on participant teachers, transcribed lessons, Content Representations (CoRes) and interviews.

Findings on Joseph's content knowledge based on his performance in the biotechnology test

Table 4.1 outlines the biotechnology test's questions and their corresponding answers. The table has first columns. The first column has the test questions while the second column has the corresponding answers. The third column presents the answers Joseph wrote (note: the answers are exactly as he gave them). The fourth column shows the marks (scores) awarded against the expected marks one would get if the answer provided was correct or partially correct. The last column shows either a comment or explanation against the provided response.

Table 4. 1: List of questions of the Biotechnology test and an outline of Joseph's responses matched against the correct answers

No.	TEST QUESTIONS	CORRECT ANSWER(S)	RESPONDENTS ANSWER(S)	MARKS AWARDED	COMMENT
1a.	Hybrid maize is produced by artificial cross-pollination. State three advantages of hybrid maize.	(i) Produce higher yield compared to local varieties. (ii) Varieties are produced to suit various ecological regions as some mature early in dry lands while others mature late where rainfall lasts longer. (iii) They adapt better to stress	(i). Produce high yields, (ii). Resistant to diseases and pests, (iii). Are drought resistant.	3/3	He correctly provided the answers
1b.	Describe how artificial cross-pollination is done.	Two maize varieties are planted in adjoining fields. All the plants of one variety are de-tasseled before they produce pollen. This means de-tasseled plants cannot self-pollinate. All their seeds are cross-pollinated with the second variety of maize	Is done by removing the tassels of a variety that we want to improve by nearby field/chains of another variety leaving the tassels intact so that pollen should transfer and pollinate another variety.	6/6	He was awarded all the marks as described the artificial cross pollination
2a.	Name three different kinds of microorganisms used in the manufacturing of industrial products.	Bacteria, Fungi, Viruses, algae	Bacteria, Virus, Fungus	3/3	He gave correct answers
2b.	Name three products produced through fermentation by yeast.	Beer, Bread, Ethanol, Carbon dioxide, Citric acid (acetic acid) Cheese, enzymes, bioplastics [3]	Carbon dioxide, Alcohol (Ethanol) and Energy	2/3	Energy was wrong because it is not an industrial product.

3a.	Define genetic engineering.	It is a process whereby useful genes are transferred from one organism into another by human manipulation/ A process that involves introducing a foreign DNA portion from a donor into a host organism to stimulate the synthesis of a protein. / Altering the genes in a living organism to produce a Genetically Modified Organism (GMO) with a new genotype ./ Altering an organism's genes by adding new genes or removing certain genes from the chromosomes.	Is a process whereby useful genes are transferred from one organism into another by human manipulation	2/2	He correctly defined genetic engineering
3b.	What is the difference between a clone and a transgenic organism?	The organism that contains a combination of genetic material from two species is called transgenic organism while a clone is a group of genetically identical organisms or a group of genetically identical cells derived from a single parent cell	A clone is an offspring where all of the genetic material in every cell is identical to that of both parents while a transgenic organism is an organism with foreign gene by genetic engineering	2/2	He correctly mentioned the difference between a clone and a transgenic organism
3c.	What do you mean by the term recombinant DNA?	An artificially made DNA strand that is formed by the combination of two or more gene sequences	Is a gene formed by joining of two DNA segments from two different sources	0/2	He wrongly defined a DNA as a gene
4a.	Where are plasmids found?	In the bacterium	In the bacteria cell	1/1	He correctly mentioned the site.

4b.	Why are restriction enzymes called “molecular scissors”?	They are able to snip chromosomes at precise points making it possible to cut out a gene from a chromosome	Because they degrade the bacterial chromosome in small pieces during replication	0/2	He used wrong vocabulary which meant breaking down the chromosomes
4c.	Name the enzyme which joins DNA fragments.	DNA Ligase	Ligase	1/1	The name was correct
5	Name any two proteins and two enzymes obtained by recombinant DNA technology.	Two proteins are Insulin and Growth hormone while enzymes are Proteases and amylase	Tissue plasminogen activator as a protein	0/4	He could not correct proteins and enzymes
6	Explain how recombinant DNA technology is useful for pharmaceutical companies.	It is used in the production of medically important proteins such as hormones and vaccines.	Microorganisms with an Eukaryotic DNA are allowed in the laboratory to produce medically important proteins. Eg. Synthetic insulin is synthesised from E. coli and used to regulate blood sugar levels in patients with diabetes mellitus.	3/3	He was able to mention the important proteins which are produced using recombinant DNA technology
7	Name any two diseases for which bioengineered vaccines have already been developed.	Rabies, Hepatitis B, Foot and mouth (Any 2)	Hepatitis B and Foot and mouth	1/2	One answer was correct while the other was wrong.

8a.	Describe three usefulness of transgenic organisms.	(i). Produce genotypes that make the plants resist pests (ii). Produce growth hormones (iii). Produce enzymes that activate blood clotting. (iv). Produce human vaccines	(i). Produce genotypes that make the plants to resist pests (ii). Produce growth hormones for rapid development in both plants and animals. (iii). Produce enzymes that activate blood clotting.	6/6	He correctly described the three usefulness of transgenic organisms
8b.	Mention two methods used in the production of transgenic organisms.	(i). By using microbes (ii). By using eggs or embryos.	(i). By using microbes (ii). By using eggs or embryos.	2/2	He correctly stated some of the methods
8c.	Describe any one method mentioned in (8b).	A specific restriction enzyme is selected. Cell culture with the required gene in the cells is obtained. Restriction enzyme cuts the DNA at two ends of the specific gene and a restriction fragment is obtained. The same restriction enzyme cuts a matching DNA sequence from a plasmid. Ligase joins the restriction fragment in the place vacated by the cut DNA segment of the plasmid. The plasmid becomes a recombinant plasmid	By using microbes - A section of DNA is extracted from an organism is translocated into bacterium or a virus. Once the bacterium has taken up the piece of DNA successfully, it may divide repeatedly into a population of bacterial cells all of which contain replicas of the foreign DNA.	8/10	He lost the two marks because he missed two important organelles in the process of producing the recombinant DNA, that is, the plasmid and the enzymes.

containing a foreign DNA fragment. The recombinant plasmids then enter the bacteria. Bacteria divide. Recombinant plasmids replicate along with bacterial DNA. A large population of bacteria containing recombinant DNA can be obtained in less than ten hours. Multiple identical copies of DNA fragments inserted into plasmids or bacteriophages are then obtained and could be transferred to specific organisms that could display the desired characteristic.

9	Describe any three ethical implications of biotechnology on society.	(i). Production of harmful organisms due to mistakes made during genetic engineering. (ii). The transgenic products may cause allergic reactions in people. (iii). Genetically identical plants and animals lead to loss of biodiversity. (iv). The new species may escape into the wild populations and superweeds could be formed by the cross-fertilisation of wild species and transgenic species. (v). Genetic change in a species is increased hence acceleration of evolution. (vi). The seed of GMOs is sterile, so the farmer is forced to buy fresh seed every year. (Any 3)	(i). Transgenic products may cause allergic reactions, (ii). Genetically identical plants and animals lead to loss of biodiversity (iii). Production of harmful organisms due to mistakes made during genetic engineering	6/6	He managed to describe the three ethical implications of biotechnology on society.

After marking the test, Joseph 47 marks out of 58 representing 79% showing that he had good content knowledge based on this test. However, he had some short falls in some success criteria as described in this section.

Joseph demonstrated an understanding of hybrid maize and pollination techniques in his answers to the first question. He correctly stated the advantages of hybrid maize and accurately described the process of artificial cross-pollination. In the answers to the second question (a and b), Joseph correctly identified the three different kinds of microorganisms that are used in industrial manufacturing (question 2a). However, in 2(b) Joseph conflated the products of anaerobic respiration with industrial fermentation. He listed carbon dioxide, alcohol (ethanol) and energy as products of fermentation by yeast when, in fact, energy is not a product of industrial fermentation. This demonstrated Joseph's misunderstanding of the specific outputs relevant to industrial contexts.

Joseph answered questions 3 (a and b) correctly, demonstrating sound knowledge in these areas. However, he incorrectly defined recombinant DNA (Q3c) as a gene formed by joining two DNA segments from two different sources. The definition he gave incorrectly identified DNA as a gene rather than a combination of gene sections from different sources. The correct definition should have highlighted that recombinant DNA is formed by combining sections of DNA from two different sources, not merely genes. The mistake Joseph made highlights a fundamental misunderstanding of the relationship among genes, DNA and chromosomes.

Joseph answered questions 4(a) and 4(c) correctly, but he gave a wrong answer to question 4(b). Question 4(b) asked why restriction enzymes are also called molecular scissors.

Joseph incorrectly stated that restriction enzymes are called molecular scissors because they degrade the bacterial chromosome in small pieces during replication. The correct answer, however, is restriction enzymes are called molecular scissors because they snip chromosomes at precise points, making it possible to cut out a gene from a chromosome. Joseph's answer incorrectly indicated restriction enzymes destroy chromosomes, and this is a fundamental misunderstanding of their function in genetic engineering.

In question 5, which asked respondents to mention two protein and two enzymes obtained by recombinant DNA technology, Joseph managed to mention the protein only but could not state the two enzymes obtained by recombinant DNA technology. The enzymes which Joseph should have mentioned include insulin and human growth hormone. The fact that Joseph could not give the examples of enzymes, it suggests that he had limited knowledge of the specific applications of recombinant DNA technology in producing enzymes.

As for question 6 and 7, Joseph answered very well. He explained very well how recombinant DNA is useful for pharmaceutical companies, which was what question 6 asked the respondents. He also correctly mentioned the two diseases for which bioengineered vaccines have been developed, which was the objective of question 7. Joseph also gave correct answers to question 8 (a, b and c). He also correctly described the three ethical implications of biotechnology on society, which was what question 9 asked the respondents to do.

Joseph's performance suggests a fair grasp of many fundamental concepts in biotechnology. He exhibited an understanding of biotechnology concepts as prescribed in the syllabus, particularly in areas such as examples of animal and plant breeding, the process of genetic engineering, applications of genetic engineering, and the ethical implications of biotechnology. However, it also brings out some gaps in knowledge. These areas should be the focus of further training and professional development to ensure a more comprehensive understanding and ability to teach these concepts effectively.

Analysis of content knowledge of Joseph based on outcome of interviews

An excerpt for the pre-lesson interview with Joseph

Researcher: Sir, what is the key concept in the lesson that you are about to teach?

Joseph: Since the lesson will take two periods, the key concepts to be covered will include the meaning of biotechnology and plant and animal breeding

Researcher: What specifically do you want your students to learn about in today's lesson and why do you think it is important?

Joseph: It is important that they appreciate how plant and animal breeding is done.

During the pre-lesson interview for his first lesson, Joseph outlined the key concepts he planned to cover. These concepts included meaning of biotechnology, plant and animal Breeding, encourage students to explore and appreciate local examples of plant and animal breeding in their surroundings, and to introduce genetic engineering. Thus, Joseph's objectives for his lesson were to understand the term "biotechnology.", to grasp the concepts of plant and animal breeding, to identify local areas where plant and animal breeding are practiced, and, finally, to have a preliminary understanding of genetic engineering. He showed the researcher the notes he intended to use and mentioned that due to time constraints, he did not develop a formal lesson plan.

In the second lesson, Joseph aimed to delve into the process of genetic engineering. His plan included: review previous lesson, use charts to describe the process of genetic engineering, and use insulin to illustrate the genetic engineering process. Thus, Joseph's objectives for his second lesson were for his students to understand the steps involved in genetic engineering, to follow and comprehend the example of insulin production through genetic engineering. Again, as was the case with the first lesson, Joseph did not have a written lesson plan for this lesson due to time constraints.

Joseph's pre-lesson interviews revealed several key points of interest. In as far as the success criteria is concerned, he effectively identified and planned to cover the success criteria outlined in the syllabus, including plant and animal breeding, applications of biotechnology, and the genetic engineering process. He also demonstrated a good understanding of the content he needed to teach and how it aligned with the curriculum. Also, his strategy to use notes and charts indicated a reliance on visual aids to enhance understanding, although the lack of formal lesson plans might suggest a need for more structured preparation. Finally, his intention to connect the lesson content with local examples showed an effort to make the lessons relevant and engaging for students.

The researcher conducted interviews with Joseph at the end of each of the lessons the researcher observed him teach. When asked to reflect on the lessons he taught, Joseph’s consolidated view was that the lessons went on well and according to his initial expectation. He also drew the researcher’s attention to the fact that, according to him, the students actively participated throughout the lessons by answering the questions he asked them. He, however, lamented the fact that many recommended textbooks contained serious errors, thus justifying why he stuck to only one textbook as his sole and primary reference source. Joseph also pointed out that he evaluated his students after each lesson to determine whether they achieved the objectives of the lesson or not, as well as how much they achieved them. Joseph attributed the errors he made during the lessons, particularly the errors associated with definition of terms and with processes, to some textbooks he used which, he admitted, contained errors.

Findings on Joseph's content knowledge based on observed lessons

Content Knowledge is, according to the consensus model, one of the main knowledge bases. Content knowledge is found in both TPBK and TSPCK. This section gives an analysis of Joseph's transcribed lessons as outlined in the preceding section. Appendix R shows part of the transcribed first lesson of Joseph.

Joseph began the lesson by engaging students with tangible examples: two packets of hybrid maize seeds. He explained that these seeds were products of biotechnology, linking the topic to something familiar to the students. He extended this connection by mentioning that certain animals and their products are also results of biotechnological processes. This approach aimed to contextualise the lesson and make it relevant to the students' everyday experiences.

Joseph employed a participatory approach to introduce the term "biotechnology". He asked students to brainstorm definitions of biotechnology, thus facilitating a class discussion. The students offered various definitions, some of which included:

- *It is the process of changing some existing organisms to become one with an aim of improving products.*

- *It is the process of reintroducing some varieties to come up with desirable characteristics.*

Joseph refined these responses, guiding the class to a more precise definition. He then provided his definition of biotechnology, which was:

"Biotechnology is the use of living organisms and their body systems to develop new and useful products that help to improve human life. Biotechnology involves the use of genetic engineering, which uses a technique called genetic engineering. Under this, they try to change the DNA molecule, which in biological terms is called recombinant DNA." He, thereafter, gave clear definitions of key terms and concepts. He also connected new content to what students had previously learned about genetics.

Throughout the introduction, Joseph described several abstract concepts, including biotechnology, which he defined clearly with practical examples, Genetic Engineering, which he mentioned but not initially defined in detail, DNA Molecule, which he identified as the material of inheritance, building on students' prior knowledge from genetics, and, finally, Recombinant DNA, which he defined explicitly with an example. Joseph defined recombinant DNA as:

> *"DNA that contains different DNA; they take DNA from one organism and DNA from another organism, they join together, they combine to make a new DNA. This means this DNA will contain information from two organisms. So, that kind of DNA coming from different organisms is called recombinant DNA."*

Joseph defined recombinant DNA as the ability to combine the DNA of one organism with the DNA of another. Joseph's verbal definition of recombinant DNA differed from the one he initially wrote on the biotechnology test he took where he stated that *"It is a gene formed by joining of two DNA segments from two different sources"* which was wrong. This shows that he had gone through the content again and had corrected his mistake. He then proceeded to state that genetic engineers can alter the DNA code of living organisms using microorganisms like bacteria, fungi, and viruses. The introduction took twelve minutes instead of the planned five, indicating a potential issue with time management.

Thereafter, Joseph introduced the methods used to improve plant and animal breeds. The first method he introduced to learners was hybridisation, which is a method to improve plants and animals by crossing different varieties of a species. He incorrectly cited Bt. Cotton as an example of a hybrid crop in Malawi produced by LUANAR. In reality, Bt. Cotton is a genetically modified organism (GMO) brought in by Monsanto and tested by LUANAR. Yet, Joseph correctly explained that manipulating the DNA of organisms results in GMOs or transgenic organisms but failed to provide local examples. He cited various research stations like Chitedze, Makoka, and Bvumbwe where students could observe hybrid production. However, he spent excessive time on this, which was unnecessary for the lesson's objectives. He accurately discussed animal breeding methods using examples of cattle and chickens.

Joseph began the second lesson by reviewing the previous lesson on biotechnology, recombinant DNA, and plant and animal breeding. He reminded students of the definition of biotechnology and asked them to state applications of biotechnology, which they did correctly due to a homework assignment. Students mentioned forensic science, blood transfusion and plant and animal breeding as applications of biotechnology. He then introduced the new lesson on genetic engineering and asked students to define the term.

One student defined genetic engineering as “a process whereby a gene is transferred by human manipulation.” Another refined it to “a process whereby useful genes are transferred from one organism to another by human manipulation.” Thereafter, Joseph defined genetic engineering as “the process of manually adding a gene into the DNA of an organism.” Joseph also defined recombinant DNA as “DNA that contains a gene from a different organism or two different DNAs that have been combined. A section of gene taken from one organism and given to another organism or then this DNA having two or the DNA that has been altered because it has been added another gene into it, that one come to be is called recombinant DNA.” He gave this definition following a vague definition by a student.

Joseph proceeded to define for the students the term transgenic organism as “an organism whose DNA has been added an extra gene or has been altered is called a transgenic organism.” He attempted to differentiate between recombinant DNA and transgenic organisms but did not provide a clear distinction. Joseph's attempt to explain the difference was not precise. The expected clarification should have been that recombinant DNA methodology is used to construct or make the gene intended to express desirable qualities while transgenic organism is an organism that has been genetically modified by inserting a gene into its genome (SMASSE, 2018).

Joseph then asked the students to give examples of microorganisms used in genetic engineering. Joseph mentioned bacteria and viruses, emphasising bacteria. He asked if students remembered the structure of a bacterium but did not provide a visual aid, such as a drawing or a diagram. He highlighted that the “part of a bacterium which is specialised for multiplication is called a plasmid” and explained its role in genetic engineering.

Joseph did not give the students definition of a plasmid and did not explain the difference or similarity between plasmids and thread-like structures called chromosomes. Instead, he posted a chart on the chalk board showing four diagrams, one of which was a chromosome and three were plasmids. He marked a part of the chromosome with 'S'. He provided three diagrams of plasmids, one intact, a circular labelled T, one with a part to be removed, and one with a gap. Thereafter, Joseph organised the students in groups and instructed them to identify a gene and a plasmid using the letters 'S' and 'T'. One group identified 'S' as a gene, explaining it forms part of the DNA in the chromosome shown in Figure 4.1.

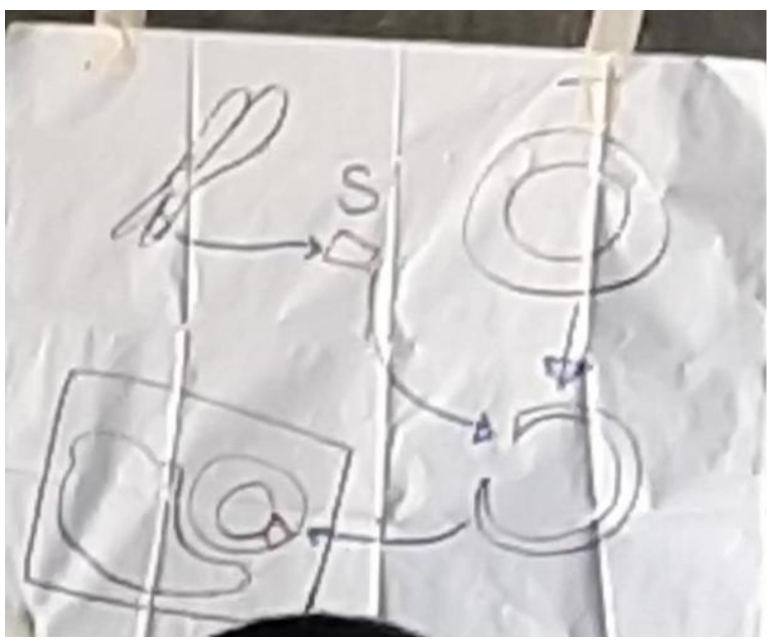


Figure 4.1: Diagram showing how genetic engineering is done

The teacher agreed with the answer the learners gave. He then consolidated with the following explanation:

> *This one is a chromosome where you will find DNA and in DNA is where you get a gene and so a gene is connected to the chromosome and this is S, so it means that the other part remaining is a plasmid.*

Thereafter, the teacher wrote on the chalkboard the following consolidated explanation:

> *A section of DNA, extracted from an organism is synthesised artificially usually translocated in a bacterium or a virus to a part called a plasmid. The bacterium or virus used in genetic engineering is called a vector; inside the bacterial cell structure is a called a plasmid, where the foreign DNA is inserted. Once the bacterium has taken up the piece of DNA it may divide repeatedly forming replicates of the DNA and this one is what we call gene cloning.*

The researcher observed that Joseph used the lecture method for the most part of the lesson, especially when describing the process of genetic engineering.

The teacher organised the learners in pairs and instructed them to describe steps of the milk production process. But the students struggled to derive the steps primarily because they missed important details from the teacher's earlier description of the process of genetic engineering using the example of insulin production. Also, the teacher hardly specified the context or details regarding milk production (for example, whether the focus was on increasing milk yield or enhancing milk quality and for which animals). The students obviously struggled because the teacher's explanation of genetic engineering was complex and did not involve interactive elements to ensure student understanding. For example, students did not get a chance to ask questions or clarify doubts during the lesson, leading to gaps in their knowledge. When it became obvious to the teacher that the students had failed to perform the task, he turned the task into a homework, instructing the learners to read from other sources and thereafter compose an essay describing the process of milk production in cattle.

Joseph showed to have some content knowledge of biotechnology concepts in the first two lessons. For example, in his introduction, he showed the students two packs of hybrid maize which he correctly described as products of a biotechnology process. He also correctly defined biotechnology as the *"the use of living organisms and their body systems to develop new and useful products that help to improve human life"* in addition to introducing other key terms in biotechnology such as genetic engineering, transgenic organisms and recombinant DNA. However, Joseph did not properly define the term recombinant DNA, highlighting a weakness in some concepts. He also could not describe the difference between recombinant DNA and transgenic organisms, resorting to giving a vague and confusing difference between the two concepts.

Joseph introduced abstract concepts of biotechnology and hurried through complex processes within a short space of time. He did not illustrate these processes on the chalkboard or on a chart and hardly gave learners opportunity to ask for clarification or any pertinent questions they might have had about the processes. This obviously was not effective as it left learners confused. Joseph also described how plant breeding takes place, using the example of maize to illustrate the process. However, he erred by citing *Bt.* Cotton, a genetically modified organism, as an example of a hybrid crop. In fact, the correct example of a hybrid crop should have been the hybrid maize that he brought for demonstration in the classroom.

Joseph described animal breeding and gave examples of animal breeding, thus accomplishing the success criteria that required students to both describe animal and plant breeding and give examples of animal and plant breeding. This was despite giving a wrong example of plant breeding. Nevertheless, the approach showed that Joseph was aware of the importance of giving his students actual examples of biotechnology to enable them understand the concept of biotechnology. Another weakness the researcher observed in Joseph's lesson was that he cited transgenic organisms as a direct result of genetic engineering without actually explaining the meaning of transgenic organisms. Nevertheless, he told the students that genetic engineering results in the production of transgenic organisms without explaining the meaning of "transgenic organisms."

Joseph began the second lesson by reviewing concepts covered in the preceding lesson on plant and animal breeding. Using a question-and-answer approach, he asked them questions on applications of biotechnology based on the reading assignment he have them in the previous lesson. The teacher only required the students to mention the applications of biotechnology and not describe them, although the success criteria requires that students describe the applications. Thus, while the students fulfilled their homework task, that is, to mention the applications of biotechnology, Joseph simply accepted the applications of biotechnology without asking the students to describe each application stated as the curriculum demanded.

After the review, Joseph delved into the day's lesson, which was on genetic engineering. Joseph demonstrated content knowledge of the process of genetic engineering by defining genetic engineering using simple words, and the students understood the meaning. He then asked the students to explain the difference between transgenic organisms and recombinant DNA. But his definition of recombinant DNA was wrong, having defined recombinant DNA as "*a section of a gene taken from one organism and given to another organism or then this DNA having two or the DNA that has been altered because it has been added to another gene into it*." This definition showed that Joseph struggled to strike the difference between a gene and a DNA.

During the lesson, Joseph reminded the students about the structure of a bacterium which he planned to use in the description of the process of genetic engineering. He also reminded the students about the plasmid, which is a part that is used for multiplication done by genetic engineering apart from the other parts such as the nucleus, cell membrane, and cytoplasm. Joseph's presentation was based on the assumption that the students knew the structure of a bacterium, but this assumption was disproved when the students failed to identify the parts of the bacterium.

Joseph simply stated that Plasmid plays a big role in genetic engineering. He used Figure 4.1 to show the process of genetic engineering using an example of insulin production. As he described the process of producing insulin, he outlined the process without specifically describing the process step by step. This method of teaching was not sufficient to help the students understand the process as, later, the students failed to come up with a similar procedure of genetic engineering. Joseph had asked the students to explain similar steps on how milk production is improved nutritionally.

Findings and analysis of interviews and transcribed lessons on teaching strategies Joseph used to teach biotechnology

This section describes the details about the teaching strategies Joseph planned to use in the two lessons he taught based on the interviews and the transcribed lessons.

Joseph's approach to teaching reflects a strong understanding of effective pedagogical strategies, particularly in making abstract concepts more accessible to students. For the first lesson, for example, which would focus on plant and animal breeding, Joseph indicated that he would introduce the lesson by showing learners a packet of hybrid maize seeds to help them understand applications and products of biotechnology in everyday life. Then he would use question-and-answer method to regularly assess the students' level of understanding of concepts in the lesson, such as, for example, meaning of terms such as biotechnology, recombinant DNA and genetic engineering. He also indicated he would use group work and pair work as a means to elicit and maintain active participation of the students throughout the lesson. Group work, as defined by Chiriac & Frykedal (2011), promotes collaborative or cooperative learning, which can enhance comprehension through peer discussions and shared problem-solving.

During the lesson, too, Joseph used demonstration which involved the use of visual aids like charts and diagrams to help demystify complex topics such as genetic engineering and insulin production. He also indicated he would use hands-on activities and field visits to provide experiential learning opportunities, making abstract concepts more concrete. For example, he incorporated field visits to agriculture research sites. These site visits will allow learners to see for themselves how plant and animal breeding is done, thus reinforcing the class discussion on how animal and plant breeding is done. At the end of the lesson, Joseph indicated he would assign a homework in which students will have to read a passage and identify applications of biotechnology.

In the second lesson, Joseph indicated he would start by evaluating the previous lesson using question-and-answer method. He would then assess the students' homework to see if they had correctly identified applications of biotechnology. He would use a chart to describe the stages of the process of genetic engineering and thereafter, based on the process of genetic engineering, organise the students in groups to derive the process of milk production. He would conclude the lesson with a summary and an evaluation exercise.

Joseph's pre-lesson interview revealed his substantial acquaintance with subject-specific and topic-specific teaching strategies. Joseph's inclusion of real-life examples, interactive questioning, collaborative work, visual aids, and continuous feedback, demonstrates a thorough understanding of effective educational practices. By starting with tangible items like packets of hybrid maize seeds, Joseph effectively bridges the gap between theoretical biotechnology concepts and students' everyday experiences. This real-life connection can help students relate better to the subject matter. His use of question-and-answer method would be valuable for checking student understanding in real-time and keeping them engaged, while at the same time sustaining active participation and critical thinking.

In addition, his emphasis on collaborative learning through group work and pair work would be vital in enhancing comprehension through peer discussions and shared problem-solving, but also aligns with constructivist principles, emphasising learning as an active, social process. Also, the use of topic-specific tools, which included visual aids like charts and diagrams, helps to clarify complex topics such as genetic engineering and insulin production, whereas hands-on activities and field visits provide experiential learning opportunities, making abstract concepts more concrete. Finally, Joseph's intensive and frequent assessments throughout the lesson is critical for learning. Regular assessment provides valuable feedback for teachers to refine their teaching methods and gives students a sense of involvement and responsibility in their learning process.

During the actual lessons, Joseph used the question-and-answer method particularly in the introduction phase to both engage the students in the learning and check their prior knowledge and understanding in relation to concepts that were to be learned in the lesson. The use of this method resonated with his pre-lesson strategy of using questions to introduce the topic and gauge student comprehension.

Joseph also used pair work and group work in both lessons. For example, Joseph used pair work when he asked students to define the term "biotechnology". In the second lesson, Joseph used group work twice, in the first instance used when he asked students to identify parts of a diagram he had shown them (Figure 4.1) and in the second instance when he asked students to devise the process of milk production. But while Joseph planned to use pair and group work as core strategies, their effectiveness was limited as the researcher observed that students struggled to engage in meaningful discussions due to a lack of understanding of come concepts.

Joseph also used the lecture method extensively to explain complex concepts like genetic engineering, recombinant DNA, and hybridisation. However, his overreliance on the lecture method deviated from his initial plan, which emphasised diverse interactive strategies. The other limitation of the exhaustive use of the lecture method is that it did not provide Joseph with opportunity to consistently check for understanding during the lectures, particularly when explaining complex processes. This oversight likely contributed to students' difficulties in subsequent group activities, such as when Joseph asked the students to use the process of genetic engineering, he described earlier to derive the process of milk production in cattle. In the second lesson, too, Joseph used a diagram to illustrate the genetic engineering process involved in insulin production. The use of visual aids such as diagrams aligns with his strategy of incorporating topic-specific tools to clarify abstract concepts in biotechnology.

At the end of each lesson, Joseph asked for student feedback. However, responses were generic, indicating a lack of detailed understanding or critical reflection. While Joseph did implement student evaluations, the superficial feedback suggests that the strategy might need refinement to be more effective.

In both post-lesson interviews, Joseph insistently indicated that all strategies he used in both lessons were effective and that the lessons went well and as he expected, judging from the observation that students actively participated in the lessons through answering questions and through the group and pair works.

However, despite Joseph’s views that the lessons went very well and were effective, the researcher observed some shortfalls with the strategies that were used. For example, the researcher observed that very few students actively participated in the tasks the teacher assigned to groups as very few and same students participated in answering questions and in making presentations. Furthermore, the researcher observed that Joseph’s overuse of the lecture method compromised student's attention to the lesson and their ability to effectively grasp abstract concepts. Joseph justified his overreliance on the lecture method on the basis of the nature of the topic he was teaching, indicating that the topic's more abstract concepts and less empirical aspects could be handled better using the lecture method than practical methods.

As regards the use of illustrations to demonstrate processes, the researcher observed that the diagram which Joseph used to illustrate the process of genetic engineering was rather sketchy and unclear. The researcher learnt during the post-lesson interview that Joseph used this sketchy and unclear diagram because he did not have adequate time to draw a better and clear diagram. This indicated his lack of seriousness and commitment to preparation.

Knowledge of teaching strategies as demonstrated in Joseph's CoRe

This section describes and analyses the teaching strategies that the Joseph wrote in his CoRe. These are the strategies which he proposed to use to teach biotechnology concepts. These teaching strategies were discussed separately because they covered the whole topic of biotechnology, unlike the previous section which used data from the pre-lesson interviews, lessons observed and post-lesson interviews only.

An analysis of Joseph's CoRe (Appendix M) showed that, in Big Idea A, Joseph would use question-and-answer and pair work to build discussions during the lesson. In Big Idea B, Joseph indicated that he would mainly use question-and-answer technique to build discussions. He further indicated he would use demonstration method to accomplish Big Idea C, under which the goal would be to help students develop detailed steps/ procedures involved in genetic engineering using the chart drawings. The CoRe further indicated the he would use brainstorming method for Big Idea D, under which students would be required to list different applications of biotechnology in the food and pharmaceutical industries. In Big Idea E, which is the last in Joseph's CoRe, the explanation method would be used to describe the ethical implications of biotechnology. Table 4.2 summarises the teaching strategies based on Joseph's CoRe.

Table 4. 2: Summary of teaching strategies as demonstrated in Joseph's CoRe

Big Science Ideas / Concepts	**Teaching strategies**
A. Historical outlook of biotechnology	Question building: Discussion. Students explain to each other in pairs what each one knows about biotechnology
B. Plant and animal breeding	Ask questions about why are plants and animals bred
C. Genetic engineering (from DNA to recombinant proteins)	Demonstration: Ask students to develop detailed steps/procedures involved in genetic engineering using the chart drawings
D. Biotechnological applications towards drugs and food production	Brainstorm a list of biotechnological applications for drugs and food production

E.	**Ethical implications of biotechnology**	Making the microscopic meaningful. Students describe the ethics and consequences of biotechnology. The class develops an explanation of the consequences of biotechnology in the ecosystem.

As can be seen in Table 4.2, Joseph systematically targeted specific concepts within each Big Idea. Somehow, he demonstrated strong awareness of teaching strategies available to him, although he could not provide justification for selecting each of the individual methods he chose to use. But in his pre-lesson interview, Joseph indicated that he would vary the methods to ensure effective lesson delivery.

During initial lesson delivery, the researcher observed that Joseph never used pair work despite mentioning it during pre-lesson interview. Instead, as the researcher observed, the lecture method dominated proceedings, thus limiting students' participation in the lesson. In fact, Joseph never mentioned the lecture method both during the pre-lesson interviews or in the CoRe. The researcher noticed that the lecture method was used in such critical discussions as the process of genetic engineering which, in fact, required a more participatory approach to be effective. There were no illustrations either on the chalkboard or on a chart paper to show the different stages of the process. This also happened when Joseph described the structure of a bacterium. Even at this stage, the whole explanation went wrong when he forgot to tell the students that a plasmid contains DNA, leading most students to conclude that only the thread-like chromosome contains DNA and not a plasmid.

During the post-lesson interview, Joseph acknowledged overly using the lecture method in his lesson, but he cited limited time as the reason for using the lecture method, indicating that learner-centred strategies would not have worked within the limited time he had for the lesson. Also, in addition to the lecture method, the researcher observed that Joseph only used the question-and-answer strategy at the expense of other practical strategies he had indicated in the CoRe such as explanation, brainstorming and demonstration. The fact that Joseph's CoRe reflected a variety of teaching strategies attests to Joseph's awareness of a variety of teaching methods and the importance of varying them during the lesson. However, he could not vary his teaching methods during the lessons, indicating his limited ability to vary teaching methods as well as to identify methods that suit the context and nature of the concepts being discussed. The overuse of the lecture method and the question-and-answer only forced students to memorise most of the content without minding to understand it.

Findings on Joseph's knowledge of students and awareness of learning difficulties

This section describes the knowledge the Joseph had before teaching a specific concept or during the planning of a lesson. It presents results that address research question three: "What knowledge of students' conceptions and learning difficulties do biology teachers have about biotechnology?" This knowledge helps teachers eliminate misconceptions that students have about a particular concept and make the content easier for students to understand.

During interviews, Joseph was able to provide insights into students' conceptions. He described his students' conceptions and learning difficulties related to biotechnology in his CoRe (Content Representation). These conceptions and learning difficulties are presented as described in his CoRe, classroom observations, and interviews.

In his CoRe, Joseph described students' perceptions, prior knowledge, and misconceptions. He noted that most students do not recognise the use of yeast as part of biotechnology. He also mentioned that students are more likely to associate ideas of plant and animal breeding with speciation rather than biotechnology (See Appendix M). Speciation, which students learned under the topic of evolution, is part of the core element of genetics and evolution, a concept introduced before biotechnology. Speciation is defined as the process through which new species originate or develop.

Joseph stated, *"Selective breeding which takes place in communities is not easily appreciated by students"* as a part of biotechnology. However, he did not explain why communities in his area did not consider selective breeding as part of biotechnology. He also mentioned that genetic engineering is difficult for students to understand because it cannot be observed directly, as the processes involved are microscopic. Additionally, the artificial production of hormones is challenging for some students to grasp because they do not relate it to the endocrine system. Joseph did not clarify how the artificial production of hormones was difficult for students to understand in relation to the endocrine system. Under Big Idea E, Joseph noted that students might struggle with understanding the ethical implications or consequences of biotechnology, but he could not explain why students had difficulty comprehending these ethical aspects.

During the interview, Joseph mentioned that students' learning difficulties included the terminology of biotechnology and concepts from genetics, which students found challenging. He identified terms such as chromosomes, plasmids, recombinant DNA, and genetically modified organisms (GMOs) as particularly problematic. Joseph discovered most of these learning difficulties during lessons, as he would ask students questions during the introduction to determine their understanding of previous lessons. This helped him connect past knowledge to new content. He did not provide lesson plans, only lesson notes, which made it difficult to see how he accounted for students' prior knowledge and preconceptions in his planning. He was able to identify some learning difficulties but did not provide reasons for these misconceptions or difficulties.

Findings on Joseph's knowledge of assessment

The findings and analysis of Joseph's knowledge of assessment, based on data from interviews, observed lessons, and his CoRe, are presented in this section.

Joseph did not show any instrument or questionnaire he would use to check students' understanding during the lessons. He did not write a lesson plan; instead, he relied on lesson notes and the textbook "Njolinjo" (2014). He stated that he would ask students questions about the concepts before teaching to check for prerequisite knowledge and after teaching to gauge understanding. Throughout the lessons, he employed the question-and-answer method and asked students to evaluate his lessons at the end such *as "How was the lesson? Did you enjoy the lesson? Where did you not understand".* However, the feedback he received was minimal, with students simply stating that the lessons were interesting and clear.

In his CoRe, Joseph listed discussion, brainstorming, demonstrations, and question-and-answer techniques as methods for assessing students. When asked if he had developed any follow-up assessment tasks, he explained that he would prepare a summative assessment only after teaching the entire topic of biotechnology, citing time constraints due to approaching national examinations. However, it was later noted that he did not administer any summative assessment after completing the topic, explaining that he had more material to cover.

In summary, Joseph demonstrated knowledge of formative assessments which was more important in this study as because it wanted to find out how the teacher was able to assess the learners during the lessons.

Findings on Joseph's knowledge of biotechnology curriculum

This section presents the finding of Joseph's knowledge of biotechnology curriculum based on the analysis of the interviews, CoRe and the lessons observed.

The results of the interview with Joseph revealed that his knowledge of the biotechnology curriculum was limited. He struggled to provide specific success criteria during interviews and relied heavily on a single textbook, *Njolinjo (2014)*, for planning and content. Joseph expressed a lack of confidence in other textbooks, citing errors, though an analysis found no errors in the books he criticised. *Njolinjo (2014)* was noted for inaccurately defining biotechnology as "the same as Recombinant DNA" (page 154).

Joseph's CoRe indicated that he referred to *Njolinjo (2014)* for lesson planning, providing only a summarised version of content for each Big Idea without detailed descriptions. For instance, under Big Idea B (Plant and Animal Breeding), he mentioned teaching the purpose of breeding but did not intend for students to learn about specific crossbreeds, although this was required by the curriculum. This discrepancy showed a basic understanding of content but a lack of alignment with curriculum demands.

Joseph intended to cover topics such as local breeding, seed selection, and beer production under Big Idea A, and to teach genetic engineering and its applications in insulin and milk production under Big Idea C. However, the curriculum required students to describe the process of genetic engineering using insulin production as an example, not just focusing on human insulin and milk. For Big Idea D, he aimed to teach about biotechnology's applications in various fields, and for the last Big Idea, the ethical and societal implications of biotechnology.

During lessons, Joseph used the *Njolinjo (2014)* textbook and did not refer to the syllabus. He demonstrated some correct content presentation but made errors, such as incorrectly explaining *Bt.* cotton. His teaching primarily relied on declarative knowledge influenced by the textbook, with limited procedural knowledge on genetic engineering.

Joseph's lesson preparation involved lesson notes and packets of hybrid maize, but he did not focus on the core subtopics such as poultry breeding and hybrid maize breeding, spending excessive time on research stations instead. He frequently used charts and illustrations but did not write lesson plans, relying on his lesson notes. Despite advising chemistry teachers to write lesson plans during SMASSE training, he did not apply the same practice to his own teaching.

Overall, Joseph’s understanding of the biotechnology curriculum was partial. He could not clearly explain specific success criteria or fully align his teaching with curriculum requirements, indicating a need for more detailed curriculum knowledge and planning.

James’ Case Profile

Background and context

James had taught biology for twelve years at the time of this study. He holds a Malawi School Certificate of Education (MSCE) and a T2 primary school teaching certificate. He had taught at four different CDSSs within the Central West Education Division before joining the secondary school at which he was recruited for this study. The total student population at James's school was 300 at the time of this study. The form 4 biology class, which he taught, had a total of 42 learners (20 males and 22 females). James reported attending SMASSE inset training every year, with specific training in biology. Despite having a primary school teaching certificate qualification that does not qualify him to teach at the secondary school level, James has been teaching at this level due primarily to the shortage of qualified science teachers in secondary schools. During his either secondary or tertiary education, he never learnt about biotechnology as a topic. All the data was generated either from the classroom or his office, from which he was operating from since he also acted as secretary for the school, as he was the only teacher with knowledge on how to use the computer in the school.

Findings on James' content knowledge of biotechnology based on his performance in the biotechnology test

Table 4.3 shows the answers James, the second participant, gave to the biotechnology test that was administered to gauge teachers' content knowledge of biotechnology concepts. The answers are copied exactly as the respondents gave them.

The first column provides the questions, while the second column provides the correct answers provided in the marking scheme. The third column responds to the participant, while the fourth column provides the score against the total marks provided for each of the questions. The last column was used to provide either a comment or an explanation on the responses provided.

Table 4. 3: List of questions of the Biotechnology test and an outline of James' responses matched against the correct answers

No.	TEST QUESTIONS	CORRECT ANSWER(S)	RESPONDENTS ANSWER(S)	MARKS AWARDED	COMMENTS
1a.	Hybrid maize is produced by artificial cross-pollination. State three advantages of hybrid maize.	(i) Produce higher yield compared to local varieties. (ii). Varieties are produced to suit various ecological regions as some mature early in dry lands while others mature late where rainfall lasts longer. (iii). They adapt better to stress	(i)They respond well to fertilizers. (ii). Some are able to adapt to conditions like drought. (iii). They produce much greater yield compared to local varieties	2/3	The first response was too general as every plant responds well to fertilizers
1b.	Describe how artificial cross-pollination is done.	Two maize varieties are planted in adjoining fields. All the plants of one variety are de-tasselled before they produce pollen. This means de-tasselled plants cannot self-pollinate. All their seeds are cross-pollinated with the second variety of maize	Two varieties of the selected plant (crop) like maize is planted in adjoined fields. The tassels of one variety are removed before they start producing pollen to avoid self-pollination. All the seeds from the detasselled plant variety are fertilised by the second variety. The seeds produced from the detasselled plant are called hybrids.	6/6	All responses were correct
2a.	Name three different kinds of microorganisms used in the manufacturing of industrial products.	Bacteria, Fungi, Viruses, algae	Bacteria, Yeast and moulds	1/3	Yeast and moulds are all fungi
2b.	Name three products produced through fermentation by yeast.	Beer, Bread, Ethanol, Carbon dioxide, Citric acid (acetic	Bread, Alcohol and acetic acid	3/3	All products mentioned are

		acid), Cheese, enzymes, bioplastics[3]			products of fermentation
3a.	Define genetic engineering.	It is a process whereby useful genes are transferred from one organism into another by human manipulation/ A process that involves introducing a foreign DNA portion from a donor into a host organism to stimulate the synthesis of a protein./ Altering the genes in a living organism to produce a Genetically Modified Organism (GMO) with a new genotype./ Altering an organism's genes by adding new genes or removing certain genes from the chromosomes.	This is a technology which involves altering the genes in living organisms to produce genetically modified organism.	2/2	He provided a correct definition
3b.	What is the difference between a clone and a transgenic organism?	The organism that contains a combination of genetic material from two species is called a transgenic organism while a clone is a group of genetically identical organisms or a group of genetically identical cells derived from a single parent cell	A clone is a group of genetically identical cells while a transgenic organism is an organism that contains genes that were inserted into it from another organism by genetic engineering.	2/2	He was able to provide a correct statement to show the difference
3c.	What do you mean by the term recombinant DNA?	An artificially made DNA strand that is formed by the combination of two or more gene sequences	Is the ability to combine the DNA of one organism with the DNA of another organism	1/2	As he provided a partial definition, a mark was deducted

4a.	Where are plasmids found?	In the bacterium	In Bacteria	1/1	The answer is correct
4b.	Why are restriction enzymes called “molecular scissors”?	They are able to snip chromosomes at precise points making it possible to cut out a gene from a chromosome	Because they cut DNA on specific recognition site known as restriction sites	2/2	He provided a correct reason
4c.	Name the enzyme which joins DNA fragments.	DNA Ligase	Ligase	1/1	He provided the correct enzyme
5	Name any two proteins and two enzymes obtained by recombinant DNA technology.	Two proteins are Insulin and Growth hormone while enzymes are Proteases and amylase	Two proteins are Insulin and Growth hormone while enzymes are Proteases and amylase	4/4	He was able to provide correct proteins and enzymes
6	Explain how recombinant DNA technology is useful for pharmaceutical companies.	It is used in the production of medically important proteins such as hormones and vaccines.	Recombinant DNA technology has helped pharmaceutical companies to modify microorganisms, animals and plants so that they yield medically useful substances.	3/3	He was able to explain how recombinant DNA is useful
7	Name any two diseases for which bioengineered vaccines have already been developed.	Rabies, Hepatitis B, Foot and mouth (Any 2)	Rabies and Hepatitis B	2/2	He provided correct diseases

8a.	Describe three usefulness of transgenic organisms.	(i). Produce genotypes that make the plants resist pests (ii). Produce growth hormones (iii). Produce enzymes that activate blood clotting. (iv). Produce human vaccines	(i). Transgenic organisms have high resistance to pests and diseases which ensures that farmers get enough harvest. (ii). Transgenic organisms have improved shelf-life such as tomatoes in agriculture sector; a gene that prevents production of an enzyme which causes softening of the tomato skin after harvesting is inserted into it. (iii). Some of the transgenic organisms like plants are able to use less water which helps in resource conservation.	6/6	He was able to describe correctly the usefulness of transgenic organisms
8b.	Mention two methods used in the production of transgenic organisms.	(i). By using microbes (ii). By using eggs or embryos, (iii). Cloning, embryonic stem cells	Embryonic stem cells and Cloning	2/2	The methods stated are correct

8c.	Describe any one method mentioned in (8b).	The appropriate DNA sequence is inserted into an in vitro culture of embryonic stem cells using homologous recombination. Foreign DNA can be introduced into Embryonic Stem cells, and utilising a selection gene, clones carrying the foreign gene can be generated. These cells can be used to make transgenic such as mice.	Embryonic stem cells, these are undifferentiated cells with the ability to multiply and differentiate into various types of cells. These embryonic stem cells can be turned into any cell type. This can help to cure various diseases such as cancer and diabetes. However, this method raises a lot of ethical issues in the sense that currently, it is only embryonic stem cells from human beings which can be used. This method is being protested by other circles saying turning human embryos into cell producers is more or less the same as terminating the life of a human being.	8/10	He lost two marks because he provided information which did not contribute to the process of carrying out the method described

9	Describe any three ethical implications of biotechnology on society.	(i). Production of harmful organisms due to mistakes made during genetic engineering. (ii). The transgenic products may cause allergic reactions in people. (iii). Genetically identical plants and animals lead to loss of biodiversity. (iv). The new species may escape into the wild populations and superweeds could be formed by the cross-fertilisation of wild species and transgenic species. (v). Genetic change in a species is increased hence acceleration of evolution. (vi). The seed of GMOs is sterile, so the farmer is forced to buy fresh seeds every year. (Any 3)	(i). Some claim that if not handled properly, DNA experiments with pathogenic microorganisms may result in the formation of infectious organisms which can cause world epidermic. (ii). Cross pollination of transgenic species and wild weeds may take place. This may result in formation of supper weeds which will affect crop production. (iii)Some people have raised concerns about the effect of genetically engineered foods on special population. For example, in infants where genetically modified foods are causing problems like allergies.	6/6	He was able to describe the ethical implications of biotechnology correctly

James scored 52 marks out of 58 representing 90%. Based on the test, James demonstrated to have good content knowledge with fewer short falls in a few success criteria (objectives) according to the syllabus as it will be described in this section.

James gave correct answers to the first question. He correctly outlined the advantages of hybrid maize and described the artificial cross-pollination of maize accurately. On the second question (Q2a), which asked respondents to state the different kinds of microorganisms used in the manufacturing of industrial products, James named bacteria, yeast and moulds. However, because both yeast and moulds fall under fungi, the respondent was awarded only two marks on this question instead of three. Likewise, James correctly identified the industrial fermentation products as question 2(b) required.

James also gave correct answers to questions 3 and 4, demonstrating a thorough understanding of the concepts covered in these questions. Likewise, in question 5, James correctly identified proteins and enzymes produced by recombinant technology. This demonstrated James' familiarity with the applications of recombinant DNA technology. This was also the case with questions 6 and 7 for which James accurately and adequately explained how recombinant DNA technology is useful for pharmaceutical companies and correctly identified two diseases for which bioengineered vaccines have been developed.

The eighth question had three parts, a, b and c. James gave correct answers to questions 8(a) and 8(b). However, although he defined transgenic organisms and correctly explained their implications and usefulness to human society, James failed to give a description of the process of either of the three methods used in the production of transgenic organisms. James answered the last question (question 9) correctly, identifying the ethical implications of biotechnology on society.

Overall, James demonstrated a solid understanding of biotechnology concepts as he answered nearly all questions correctly. However, he demonstrated gaps in knowledge in as far as the process of using embryonic stem cells is concerned. This was despite his ability to explain the importance and implications of the process.

Analysis of content knowledge of James based on outcome of interviews

This section presents the analysis of content knowledge of James based on the semi-structured interviews conducted.

The researcher observed from the pre-lesson interview with James that the objectives of his first lesson were that, by the end of the lesson, students should be able to explain the meaning of biotechnology and to explain how animal and plant breeding are done in Malawi. He cited his students' prior knowledge of the meaning and types of variations among living organisms from the topic of genetics, as well as their experience of how people select seeds or animals with desirable characteristics, as the knowledge that would help them easily understand concepts to be covered in the lesson. The researcher also learnt through the pre-lesson interview with James that he planned to teach genetic engineering.

Through the pre-lesson interview, too, the researcher established that James prepared lesson plans for both of the lessons he planned to teach. He also had a clear plan and approach of how he was to handle the two lessons. For example, with reference to the second lesson, James explained that he would first use a question-and-answer approach to assess the students' understanding of the concepts learned in the previous lesson, that is, animal breeding and plant breeding. Thereafter, he would probe the students' prior knowledge of concepts of biotechnology before actually introducing the process of genetic engineering. Then, after introducing genetic engineering, he would give the students textbooks describing the process of genetic engineering and instruct them to read and summarise the steps of the process of genetic engineering.

During the pre-lesson interview, too, James showed the researcher a chart that illustrated the steps of the process of genetic engineering which he was going to use to describe the process of genetic engineering. All these strategies and approaches were reflected in the lesson plans he had developed and which the researcher saw. All these showed that James prepared his lessons very well and that he amassed a good level of content knowledge.

Excerpt for post-lesson interview with James

Researcher: How did the lesson go?

James: The lesson was Ok, of course I observed some of the shortfalls. The first one was on the definition, biotechnology. I think I did not clearly clarify on the responses which the learners gave. I did not dwell much of that so that I can iron out some of the things which may be were not supposed to be there.

Researcher: But I saw you underlining one of the phrases from the students which you were trying to link to your definition.

James: Yes, but another problem was time management, I think may be, I gave them two questions. To them it was a little bit, it gave them tough time because I asked them, to mention some of the areas in Malawi where hybridization is done and then they should give examples. Now their mentality was that they will find everything in the textbooks provided. So they had to struggle because I could hear some of them saying we have tried, some of them had to discuss. So I told them that they have to think

Researcher: So, what could be your conclusion about the lesson?

James: The lesson went on as I had planned it.

Researcher: Any challenges?

James: Yes, Materials. We don't have enough pental pens, I forgot to take a sell tape and I had to ask a student to go to the staffroom to collect.

Researcher: Any other challenge?

James: No

Researcher: What is your plan for the next lesson?

James: I will plan it carefully so that I clarify the areas I feel they did not understand in this lesson and continue to the unknown subtopic, genetic engineering.

During the post-lesson interview, James acknowledged that he used lesson plans which he developed to teach all his lessons and to guide him how he was going to handle the lesson. In fact, according to the researcher's findings, James was the only one of the three study participants to have developed and followed a lesson plan during his lessons. The fact that James developed and used a lesson plan in all his lessons demonstrates his strong commitment to maintain structured, focused and effective teaching.

In the post-lesson interview, James also acknowledged he used a variety of recommended textbooks such as Chimotcha & Lungu (2017), Avis et al (2018) and other sources to prepare content. He also highlighted that he employed clear illustrations and visual aids for explaining complex concepts like genetic engineering. To promote students' participation throughout the lesson, James indicated in the post-lesson interview that he used group work, pair work, question-and-answer and brainstorming. He also highlighted his use of peer teaching which he managed to incorporate by allowing at least one student to teach peers. To ensure that as many students as possible understand the concepts under discussion, James indicated that he regularly asked the students if they understood each step of processes like genetic engineering, thus also ensuring continuous engagement.

On the other hand, James lamented that limited time allocated to the lesson compromised his initial plan for the lesson. James struggled to keep lessons within the planned time frame. One of the factors contributing to this, as the researcher also observed during the lessons, was allowing students more time than planned for presentations, thus forcing him to modify his lesson structure. Another weakness that James also cited as affecting his lesson was the students' inability to provide answers during lesson reviews. In the post-lesson interview, James attributed this to a lack of study on the part of the students.

Findings on James' content knowledge based on observed lessons

This section describes the two transcribed lessons which James taught and the researcher observed. The description of the lessons is followed by an analysis which establishes critical implications about content knowledge of biotechnology. Appendix S shows part of the transcribe lesson taught James.

James began his first lesson on animal and plant breeding by reviewing knowledge students had acquired from their earlier discussion of genetics, probing their knowledge of meaning and types of genetic variations among organisms. Thereafter, James introduced the day's lesson topic, which was biotechnology. He asked the students to brainstorm the meaning of biotechnology, prompting two students to give two different definitions of the term. James then consolidated from the suggestions of the students by defining biotechnology as *"the utilisation of the organisms or part of the organism or their processes to produce either living organisms or to produce things for human benefit".*

After giving a consolidated definition, James organised the students into groups, assigned a textbook to each group, and instructed each group to read a passage and identify the different varieties of maize and other crops produced by different companies in Malawi. James wrote the topic of discussion on the board which was “Animal and Plant Breeding in Malawi” before inviting the students to present their findings. James noticed he had limited time, and that it would be impossible based on this to have every group present their findings. So, he only invited one group to present their findings and informed the rest of the groups that they would present their findings during the next lesson.

Due to time limitations, James deferred some group presentations to the next lesson. He then summarised the topic on plant and animal breeding, explaining how plant and animal breeding. In his description of plant breeding, he pointed out that hybrid seed production is widespread in Malawi, with many companies involved in breeding of plant species. He also made the point that maize breeding is done primarily obtain early maturing maize varieties and to obtain high yielding varieties that can produce huge quantities in small cultivation fields. As for animal breeding, he used the example of notable poultry breeds which are crossbred with local poultry breeds to produce improved breeds in Malawi. He mentioned the Black Astro breed which is crossbred with indigenous chickens. The Black Astro is notable for its larger size, more meat and higher egg production. This breed is cross-bred with indigenous breeds which are known for their resistance to disease and adaptation to local conditions. Thus, crossbreeding the Black Astro with the indigenous variety yields a breed with more desirable traits. He also mentioned that crossbreeding occurs in dairy cattle as exotic breeds of cattle are crossbred with local breeds to produce breeds with high milk yield and high resistance to disease. All the content James presented in this lesson was consistent with what was in the approved textbooks and what is suggested in the syllabus.

James began the second lesson by reviewing the content he taught in the previous lesson. Again, using a question-and-answer method, James asked the students review questions on plant and animal breeding and on application of biotechnology in different fields. The students visibly struggled to answer the questions, and the teacher resorted to probing questions to assist the learners to remember what was learnt in the previous lesson. In the process, the teacher also addressed serious misconceptions among some students concerning application of biotechnology (that is, he corrected a student's misconception about bacteria being used in beer brewing, clarifying that yeast is used instead).

Thereafter, James introduced the day’s lesson, which was genetic engineering. The objective of the lesson was to enable learners describe the process of genetic engineering. He asked students to brainstorm the meaning of the term genetic engineering, which none of the students was able to define. James then quickly organised the students in pairs, instructing them to suggest definition genetic engineering. The pair discussions resulted in four proposed definitions which the teacher built from to give a correct definition.

James validated all four definitions of genetic engineering the students had proposed from their discussions. After the discussion of definitions, James organised the students into six groups, gave each group a textbook containing a section describing the process of genetic engineering, and instructed each group to read and summarise the process of genetic engineering, paying attention to the tools used in the process and the procedural steps that are involved. The students were informed they would present their work in class.

The first group presented its summary of the process of genetic engineering, paying specific attention to the tools used and the steps involved. A second group also made its presentation, but the presentation was very similar to the one by the first group. The teacher noticed that both presentations committed errors concerning the actual steps, and he remedied the shortfalls by posting a chart illustrating the process in its correct order on the chalkboard. He drew the attention of the students to the fact that bacteria are commonly used in the process of genetic engineering due to their fast multiplication and presence of plasmids. He also demonstrated how a section of DNA could be cut, removed, and replaced with DNA from another organism.

The teacher described the process as follows:

> *First of all, you should have the bacteria from which you obtain the plasmids. These plasmids have got a site where you are supposed to insert your required genes or section of DNA. Each plasmid has got a site, called the restriction private site of the DNA. This site is where you would insert your foreign DNA. You have to take the restriction endonuclease enzyme which acts as molecular scissors. Suppose that you want to take a certain trait of a certain variety of crop which produces high yield, what you need to do is to cut a section of the plasmid using the restriction endonuclease enzyme. You use the same restriction enzyme to cut the section of the DNA of a plant where the required trait is found. So, number one says the plasmid is removed from the bacterium and a section of its DNA is cut by the restriction enzyme. This section of the plasmid is removed containing the DNA controlling the trait you want to improve thereby creating a gap. Now you have got this foreign DNA containing*

the required genes for the trait you want which is the high yield that you need. The foreign DNA is also cut by the same enzyme. Once you have done that, what do you do, you go to step number 3. The foreign DNA is now inserted into the T-DNA of the plasmid. Now from there you can take this plasmid and put it back into the bacterium there the bacterium is put into a culture medium and placed at a normal temperature. Then you allow the bacteria to start to multiply and at the same time, it is also producing or multiplying or producing the foreign DNA containing the required traits you are looking for. They have to be put into a gene library where they are stored so that whenever you want to transfer this gene containing the required traits, then you just go to the gene library then you transfer it to the plant so that the plant can produce more yield. So that's the process of genetic engineering.

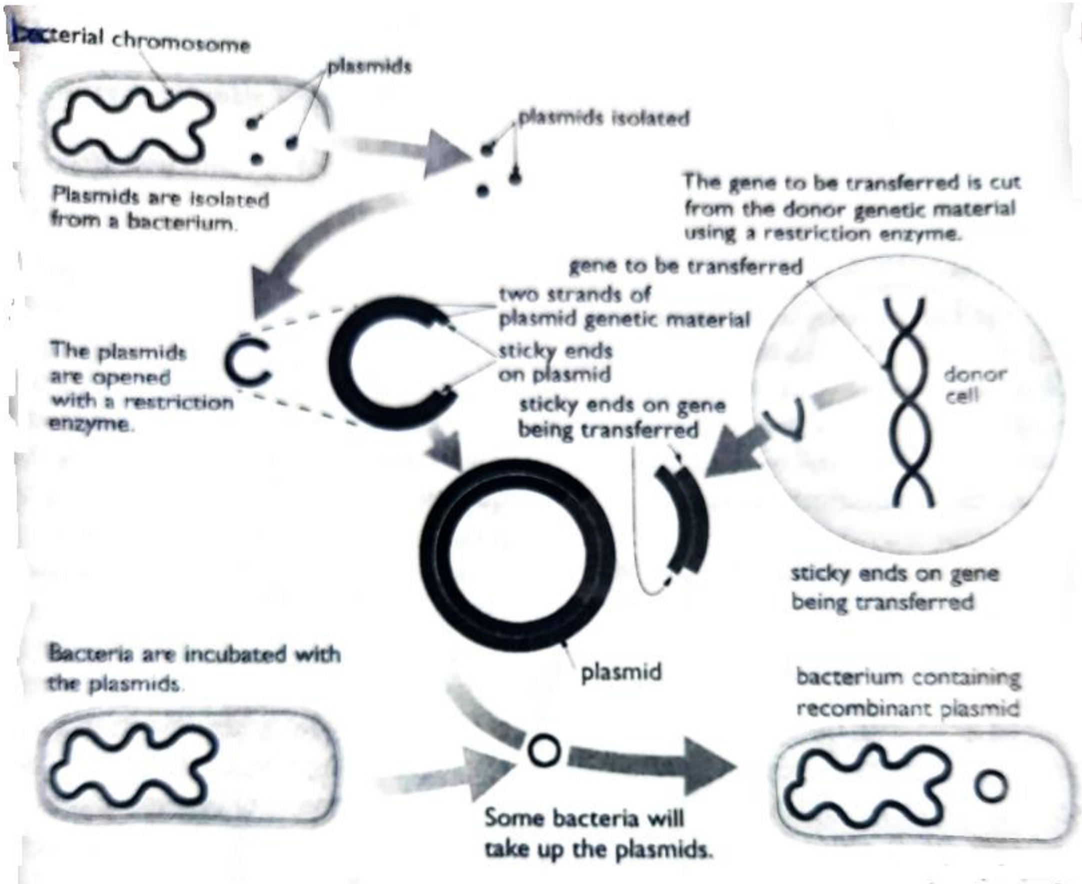


Figure 4.2: Diagram showing the process of genetic engineering (Stages of producing a transgenic bacterium (Source: Avis et al, 2018, pp 133).

James utilised a clear and well-labelled chart (Figure 4.2) from Avis et al. (2018) to illustrate the stages of producing a transgenic bacterium. He also correctly identified the tools that are used in genetic engineering, such as cell structure, restriction enzyme, plasmid, host bacteria and ligase. However, at some point, he introduced content that was beyond the level of the students and not prescribed in the syllabus (that is, T-DNA). This was further complicated because he did not explain this concept.

Some students even struggled to understand how molecular glue works, despite the teacher explaining it in detail using a chart. To help students grasp the concept, the teacher used a practical example, in which he cut a piece of paper to represent the plasmid, cut another piece from a different paper to represent foreign DNA, and used glue to stick the new piece into the gap of the original paper. He then compared this to the genetic engineering process where ligase seals the foreign DNA into the plasmid, ensuring the two ends are intact. In his summary, the teacher took the students through the entire process of genetic engineering once more, and then informed the students what they would learn in the next lesson, which was insulin production and other applications of biotechnology.

James showed to have content knowledge and applied it effectively in his teaching. He also demonstrated strong organisation of the lessons and a good class control which was aided by the lesson plans he developed prior to the lessons. James started each lesson by reviewing prior content, ensuring continuity and reinforcing student understanding. For example, he reviewed the previous lesson on variations, linking it to the new topic of biotechnology. He also utilised students' prior knowledge and harnessed it well to help lead learners into current lesson objectives. For instance, he asked students to define biotechnology to gauge their prior knowledge and then provided a correct definition. This approach aligns with the knowledge base of understanding students' pre-existing knowledge.

James also promoted students' active participation during lessons. He used question-and-answer, brainstorming, pair work and group work to make sure students were engaged throughout the lesson. For example, at some points, James distributed different textbooks and had students summarise passages on plant and animal breeding in groups. This method encouraged collaborative learning and exposed students to various perspectives on the same topic. Students presented their summaries, and James facilitated discussions, expanding on their points and providing additional examples. Also, in relation to teaching meaning of terms, when students struggled to define key terms, James encouraged pair discussions, leading to better student-generated definitions which he synthesized into a clear, comprehensive explanation.

James also used concrete examples and visual aids to support learning and concept mastery. For example, James used a chart (Figure 4.2) to explain genetic engineering and employed practical analogies, such as cutting and gluing paper, to clarify complex processes like the use of ligase as molecular glue. James also corrected misconceptions and used concrete examples to aid understanding.

Findings and analysis of interviews and transcribed lessons on teaching strategies James used to each biotechnology

This section presents the findings and analysis of teaching strategies for James from interviews and the transcribed lessons.

The researcher identified question-and-answer methods, group work and demonstration as core teaching strategies James planned to use to teach biotechnology. James indicated that he would use question-and-answer method in both of his lessons. In the instance of the first lesson, James indicated he would use question-and-answer method during the introduction to review students' knowledge of concepts on the topic of genetics, which he would then use to introduce the lesson's topic "biotechnology". As in the case of the second lesson, James would use the question-and-answer method to assess students' achievement of concepts learned in the previous lesson and then use the outcomes of the assessment to introduce the day's lesson (i.e. genetic engineering).

In addition to the question-and-answer method, James also indicated he would use group work to teach concept in biotechnology. For example, in both the first and second lesson, James indicated he would assign tasks to students, assign different textbooks to them, have them read, summarise and present their findings on the tasks assigned to them. He indicated this would be important in encouraging active learning, collaboration, and deeper understanding as students explain concepts to each other. James indicated that he deliberately planned to primarily be a facilitator throughout the lesson, allowing students to take the lead in reading, discussing, and summarising content. He would only step in to clarify points and correct misconceptions.

Finally, James indicated he would use visual aids or demonstrations. For example, in the first lesson, James planned to use charts and representations to summarise key points. In the second lesson, James said he would conclude the lesson with important points highlighted through visual aids.

James' approach, as highlighted in the pre-lesson interview, reflects a strong awareness and understanding of both subject-specific and topic-specific teaching strategies. By leveraging participatory methods like group work, peer teaching, and using visual aids, he creates an interactive and student-centred learning environment. This method not only engages students but also encourages them to take ownership of their learning process.

During the actual lessons, the researcher observed that James used question-and-answer, group work and demonstration in both of his lessons. In his introduction of the first lesson, James used the question-and-answer method to assess students' prior knowledge and ensure they understood the previous lesson. James concluded each lesson with a question-and-answer session to check for understanding. This method effectively engaged students, refreshed their memory, and set the stage for new learning. It also effectively assessed student comprehension and addressed any remaining questions, ensuring that students understood key concepts of the topic.

James used group work twice in each of the two lessons the researcher observed. He provided different textbooks for students to read, summarise, and present on topics like plant and animal breeding and the genetic engineering process. Group work promoted collaborative learning and peer teaching, allowing students to learn from each other and reinforce their understanding through discussion and presentation.

After group presentations, James clarified misunderstood areas using the chalkboard and well-drawn illustrations. He took time to explain genetic engineering process step by step. This approach ensured that all students had a clear understanding of complex topics. Visual aids and step-by-step explanations helped in solidifying their grasp of the material.

James demonstrated the ability to use both subject-specific and topic-specific teaching strategies, fostering an interactive and student-centred learning environment.

In his post-lesson interview, James hinted that the question-and-answer technique was particularly effective in engaging students and checking their understanding. He pointed out that students were able to respond well to questions, indicating that this method helped reinforce their learning and allowed for real-time assessment of their comprehension.

With reference to the use of group work, James acknowledged that group work that involved reading and summarising textbook passages on genetic engineering proved challenging for many students. He noticed that many students struggled to understand and summarise the content, leading to incomplete or incorrect presentations. Only a few students managed to accurately comprehend and summarise the material for their groups. It is probable that this method might have been relatively new to students, causing difficulties in adaptation. Also, the complexity of the textbook passages might have been too high for the students' current reading and comprehension levels.

James also observed that students performed better when they discussed specific questions rather than summarising textbook content. Thus, discussions around focused questions rather than content were more engaging and productive, indicating that students could better understand and articulate their thoughts in this format.

Knowledge of teaching strategies as demonstrated in James' CoRe

This section describes and analyses the teaching strategies that the James wrote in his CoRe. These are the strategies which he proposed to use to teach biotechnology concepts. These teaching strategies were discussed separately because they covered the whole topic of biotechnology, unlike the previous section which used data from the pre-lesson interviews, lessons observed and post-lesson interviews only.

In his CoRe, James also described the teaching strategies he was going to use to teach each of the Big Ideas he listed (see Appendix N). The main teaching strategies he highlighted in his CoRe included think, pair and share, discussions, field visit, resource persons, explanation, question-and-answer, brainstorming and debate. The CoRe reflected James' broader knowledge of the teaching strategies available to him to teach concepts in biotechnology as these strategies are also suggested in the curriculum. Table 4.4 summarises James' CoRe.

Table 4. 4: Summary of teaching strategies as demonstrated in James' CoRe

Big Science Ideas / Concepts	Teaching strategies
A. Historical outlook of biotechnology	Think pair and share: in which learners will think on their own, that is, the meaning of biotechnology thereafter sharing their responses with their friends. Discussions: where students discuss the historical background of biotechnology
B. Plant and animal breeding	Discussions: learners are involved in discussions on the application of biotechnology in different disciplines thereafter presenting their findings in a plenary. Field visit: Arrange a field visit to one of the sites where the application of biotechnology is being used like the Chitedze research station to learn how the production of new varieties of maize is being done or visit a local beer brewer to see how biotechnology is applied. Use of resource person: who is knowledgeable on issues of biotechnology carried out in his area of specialisation
C. Genetic engineering (from DNA to recombinant proteins)	Discussions: learners discussing the materials required for genetic engineering Explanations: learners/teachers explaining the process of genetic engineering

	Questions and answers: where learners will be involved in giving responses posed to them by the teacher or fellow learners.
D. Biotechnological applications towards drugs and food production	Discussions: where learners will be asked to brainstorm the production of insulin. Brainstorm: learners will be asked to brainstorm other applications of biotechnology.
E. Ethical implications of biotechnology	Discussions: learners to discuss the benefits and disadvantages of biotechnology. Debate: learners to be involved in a debate on the advantages and disadvantages of biotechnology.

An analysis of James' CoRe, data collected from interviews with him, lesson plans, as well as data from initial lesson observations shows that James used most of the strategies which he indicated would be used to teach concepts in biotechnology. For example, the researcher observed that James adequately used and varied many learner-centred teaching strategies, such as use of concrete objects and illustrations. However, he did not engage resource persons citing inadequate time as a hindrance to implementing these strategies. He could not use field visits because the number of the periods the topic has could not accommodate it unless the teacher uses the time outside the timetable. The researcher also observed that, at some point, James rushed through important concepts using the lecture method when, in fact, these concepts required more participatory methods to teach them to students. Again, James cited inadequate time as the reason that prompted him to resort to the lecture method.

The researcher observed during the first lesson that James used a question-and-answer technique to probe students' knowledge of concepts in genetics. This approach was mentioned in his CoRe and was used effectively. With reference to group work, James organised students into groups of six and assigned a textbook to each group. In the first lesson, he instructed each group to read an assigned passage on plant and animal breeding in Malawi and make a summary based on the passage. During the second lesson, he also did the same, and asked the students to summarise the process of genetic engineering. In both cases, each group was required to make a presentation based on the task. However, James did not indicate in his CoRe that he would use the textbooks. Also, the use of group work consumed a huge amount of time, forcing him to suspend equally important participatory methods such as discussion and pair work which also appeared in his CoRe.

When it came to the students to read a passage on the process of genetic engineering and make a summary of the process, the student struggled to identify the stages of the process, although they managed to list the tools used in genetic engineering. James' presentation of the process of genetic engineering was clear. He presented the stages of the process clearly on a chart paper and even used concrete objects to show how the molecular glue works when students had asked him how the DNA segment is glued to the plasmid. However, he confused students by including content that was beyond the level of MSCE.

Findings on James' knowledge of students and awareness of learning difficulties

This section describes the knowledge the James had before teaching a specific concept or during the planning of a lesson. It presents results that address research question three:

“What knowledge of students’ conceptions and learning difficulties do biology teachers have about biotechnology?”

During interviews, James was able to provide insights into students' conceptions. James also provided lesson plans used in teaching, offering evidence of prior knowledge or prerequisite knowledge. He described his students' conceptions and learning difficulties related to biotechnology in his CoRe (Content Representation). The section outlines these conceptions and learning difficulties as described in his CoRe, classroom observations, and interviews.

James’ knowledge of students’ conceptions and learning difficulties in biotechnology, as derived from his CoRe, was presented and compared with his statements during interviews. James identified both prior knowledge and misconceptions that students may have. Given that biotechnology is a new topic in the curriculum, he highlighted numerous misconceptions for each Big Idea (Appendix N). He explained that correcting these misconceptions would help students understand various concepts and processes, such as transgenics and genetic engineering, and how biotechnology is applied in fields like agriculture, medicine, and forensic science.

James outlined a few difficulties associated with teaching Big Ideas B, C, and D in his CoRe (Appendix N). He attributed many of these difficulties to a lack of teaching and learning materials and a lack of expertise to conduct biotechnology experiments, as they were not suggested or provided in the syllabus. James was the first participant to express an awareness of his own knowledge limitations. He stated, “*As you are aware, I did not go beyond MSCE; therefore, my knowledge is limited to MSCE. I am forced to read more so that I can deliver in the class.”* He explained that the curriculum did not offer clear experiments he could perform with students, as he had never studied biotechnology in secondary school or at the Teachers' College of Education. Despite its inclusion in the syllabus, the actual application of biotechnology in classes was generally restricted, making it difficult for students to understand and appreciate the subject.

In explaining his lesson plans, James provided some prerequisite knowledge he expected his students to have before teaching a particular concept. He often used what he had taught in previous lessons as a foundation for new content. For example, before introducing biotechnology as a new topic, he asked students questions related to genetics. This strategy helped connect what students already knew to the new material. During interviews, James mentioned that students had many misconceptions about biotechnology and that he had to teach the concepts in a way that encouraged full participation in class discussions. However, he could not provide specific examples of misconceptions his students had, indicating that he only assumed students might have problems with various biotechnology concepts.

Findings on James' knowledge of assessment

This section presents the findings on knowledge of assessment based on the interviews and the content representation (CoRe) of James.

During pre-lesson interviews, James showed some questions he had prepared to ask students, which he included in his lesson plans for both the introduction and conclusion of the lessons. Throughout the lessons, he periodically asked recall and comprehension questions to ensure students understood each concept before moving on to the next. In post-lesson interviews, James consistently mentioned that he wanted to give assessments after teaching each concept but was unable to due to time constraints. As a result, he opted to give a short test at the end of the topic.

In his CoRe, James described various formative assessment methods he intended to use during lessons, such as question and answer, brainstorming, and debate. However, in practice, he mainly used the question-and-answer technique and did not provide any written assessments during the lessons. James was also observed using observation as an assessment method when students engaged in group work activities. Similar to Joseph, James strictly followed the order of topics as laid out in the syllabus.

In summary, James demonstrated an understanding of formative assessment as he was able to use it throughout his lessons.

Findings on James' knowledge of the biotechnology curriculum

This section presents the findings of James' knowledge of the biotechnology curriculum based on the interviews, different documents such as the schemes of work, lesson plans, and the CoRe.

The findings from the interview with James highlighted his thorough understanding of the biotechnology curriculum. He demonstrated a strong grasp of curriculum details and successfully utilised various resources in his lesson planning and implementation.

James exhibited a clear understanding of the biotechnology curriculum. For instance, he accurately referenced the success criteria from the syllabus, such as giving examples of animal and plant breeding and describing how artificial breeding is done in plants, poultry, and cattle. He had detailed knowledge of what students were expected to learn, showing familiarity with the curriculum's requirements and success criteria.

James presented a comprehensive set of resources, including the syllabus, schemes of work, lesson plans, and multiple textbooks: *Avis et al. (2018), Njolinjo (2014), Chimocha & Lungu (2017),* and *Nsasa (2018).* He also referenced a write-up on Biotechnology from a SMASSE workshop, indicating a wide range of materials used for lesson preparation. His lesson planning was aligned with the specific success criteria from the curriculum, focusing on delivering relevant content without overstepping secondary school level expectations.

James used his CoRe effectively, detailing what he intended students to learn under each Big Idea. His teaching covered various aspects of biotechnology, including its impact, applications, and scientific relevance. Although James had extensive knowledge about the history of biotechnology, he chose not to emphasize Big Idea A as much, focusing instead on the other Big Ideas and providing detailed content and explanations.

He identified common student misconceptions about biotechnology, such as the application of biotechnology at home and its use in food production and genetic engineering. He also stressed the importance of understanding biotechnology's implications to help students make informed decisions.

James employed a variety of teaching strategies and resources, including textbooks, chart papers, and group work activities. He effectively integrated declarative, procedural, and conditional content knowledge into his lessons. Despite his thorough planning and detailed content, James faced challenges with time management, as his lesson content often exceeded the available time.

In conclusion, James demonstrated a superior understanding of the biotechnology curriculum compared to Joseph and John. His ability to integrate various resources, align with curriculum requirements, and detail the content for each Big Idea underscored his strong curriculum knowledge. However, time management issues highlighted an area for improvement. Overall, James's comprehensive approach to planning and teaching reflected a high level of curriculum proficiency.

John's Case Profile

Background and context

At the time of this study, John had taught biology at the secondary school level for seventeen years. He possesses a diploma in education with biology and mathematics as his subjects of specialisation. He had taught biology at the school of study for four years when the study commenced. There was a total of 400 students at the school John taught at the time of this study, and the form 4 biology class, which he taught, had 60 students (29 males and 31 females). In addition to teaching biology, John also taught agriculture. He is a seasoned participant in SMASSE inset programs, and he reported having attended a couple of mathematics sessions of SMASSE divisional trainings. During his either secondary or tertiary education, he never learnt about biotechnology. All the data was generated within the school where he was teaching. This was either in class or in his office, which was part of the library.

Findings on John's content knowledge of biotechnology based on his performance in the biotechnology test

Table 4.5 presents the responses of John, a third participant who took the biotechnology test. The answers presented in the table are the exact answers that John wrote.

The first column provides the questions, while the second column provides the correct answers provided in the marking scheme. The third column responds to the participant, while the fourth column provides the score against the total marks provided for each of the questions. The last column was used to provide either a comment or an explanation on the responses provided.

Table 4. 5: List of questions of the Biotechnology test and an outline of Johns' responses matched against correct answers

Ser No.	TEST QUESTIONS	CORRECT ANSWER(S)	RESPONDENTS ANSWER(S)	MARKS AWARDED	COMMENTS
1a.	Hybrid maize is produced by artificial cross-pollination. State three advantages of hybrid maize.	(i) Produce higher yield compared to local varieties. (ii). Varieties are produced to suit various ecological regions as some mature early in dry lands while others mature late where rainfall lasts longer. (iii). They adapt better to stress	(i). It produces yields twice as much compared to available varieties in Malawi, (ii). It is insect resistant (iii). It is herbicide resistant	1/3	He provided completely wrong 2 answers which do not apply to hybrid maize
1b.	Describe how artificial cross-pollination is done.	Two maize varieties are planted in adjoining fields. All the plants of one variety are de-tasselled before they produce pollen. This means de-tasselled plants cannot self-pollinate. All their seeds are cross-pollinated with the second variety of maize	By transferring pollen from anthers of a flower to the stigma of another flower	2/6	Instead of describing artificial cross pollination he simply stated how pollination takes place
2a.	Name three different kinds of microorganisms used in the manufacturing of industrial products.	Bacteria, Fungi, Viruses, algae	Fungi, Bacteria, Moulds	2/3	Moulds are a form of fungus which he stated already, hence 2 marks
2b.	Name three products produced through fermentation by yeast.	Beer, Bread, Ethanol, Carbon dioxide, Citric acid (acetic acid), Cheese, enzymes, bioplastics [3]	Cheese, Scones, Local bread (Mandazi)	2/3	Scones and mandazi are the same, hence he lost one mark

3a.	Define genetic engineering.	It is a process whereby useful genes are transferred from one organism into another by human manipulation/ A process that involves introducing a foreign DNA portion from a donor into a host organism to stimulate the synthesis of a protein. /Altering the genes in a living organism to produce a Genetically Modified Organism (GMO) with a new genotype.	It is the process of altering the genes in a living organism to produce a genetically modified organism (GMO) with a new genotype.	2/2	He was able to provide the correct definition
3b.	What is the difference between a clone and a transgenic organism?	The organism that contains a combination of genetic material from two species is called a transgenic organism while a clone is a group of genetically identical organisms or a group of genetically identical cells derived from a single parent cell	A clone is a group of genetically identical cells derived from a single parent cell while transgenic organisms are organisms that result from organisms whose genes are manipulated to produce the desired characteristics	2/2	He was able to differentiate a clone from transgenic organism
3c.	What do you mean by the term recombinant DNA?	An artificially made DNA strand that is formed by the combination of two or more gene sequences	It is the ability to combine the DNA of one organism with the DNA of another organism	2/2	He was able to provide a correct definition

4a.	Where are plasmids found?	In the bacterium	This is DNA found in bacteria	1/1	This is correct microorganism
4b.	Why are restriction enzymes called “molecular scissors”?	They are able to snip chromosomes at precise points making it possible to cut out a gene from a chromosome	Because they are used to cut out the bacteria DNA at exact the same place to produce two "sticky ends"	2/2	This is a correct reason for restriction enzymes
4c.	Name the enzyme which joins DNA fragments.	DNA Ligase	It is DNA ligase	1/1	The enzyme stated is correct
5	Name any two proteins and two enzymes obtained by recombinant DNA technology.	Two proteins are Insulin and Growth hormone while enzymes are Proteases and amylase	Two proteins are erythropoiten and interferon and enzymes are restriction enzyme and alkaline factitase	2/4	The proteins he wrote were correct but the enzymes were all wrong
6	Explain how recombinant DNA technology is useful for pharmaceutical companies.	It is used in the production of medically important proteins such as hormones and vaccines.	Altering genetic material outside an organism to obtain enhanced and desired characteristics in living organisms or as their products	0/3	The answer he provided shows that either he did not understand the question of he didn’t know the answer
7	Name any two diseases for which bioengineered vaccines have already been developed.	Rabies. Hepatitis B, Foot and mouth (Any 2)	HIV prevention vaccine and Covid-19 vaccine	1/2	He provided one correct vaccine which was for Covid-19

8a.	Describe three usefulness of transgenic organisms.	(i). Produce genotypes that make the plants resist pests (ii). Produce growth hormones (iii). Produce enzymes that activate blood clotting. (iv). Produce human vaccines	(1). Used in medicine to produce insulin. (2). To produce hormones that treat diseases (3). Inject vaccines into foods to avoid the difficulty of administering shots	4/6	He provided a wrong answer which showed that he did not know exactly how useful transgenic organisms are.
8b.	Mention two methods used in the production of transgenic organisms.	(i). By using microbes (ii). By using eggs or embryos, DNA microinjection	DNA microinjection; Embryonic stem-cell mediated gene transfer	2/2	He provided correct methods
8c.	Describe any one method mentioned in (8b).	The most common method used to date is the microinjection of genes into the pronuclei of zygotes. a transgenic DNA construct is physically microinjected into the pronucleus of a fertilised egg. The injected embryos are subsequently transferred into the oviducts of pseudo-pregnant surrogate mothers such as cows or sheep.	DNA microinjection is the process of transferring genetic materials into a living cell using glass micropipettes or metal microinjection needles. DNA or RNA is injected directly into the cell's nucleus.	6/10	He was able to provide 3 steps out of five required to get all the 10 marks

9	Describe any three ethical implications of biotechnology on society.	(i). Production of harmful organisms due to mistakes made during genetic engineering. (ii). The transgenic products may cause allergic reactions in people. (iii). Genetically identical plants and animals lead to loss of biodiversity. (iv). The new species may escape into the wild populations and superweeds could be formed by the cross-fertilisation of wild species and transgenic species. (v). Genetic change in a species is increased hence acceleration of evolution. (vi). The seed of GMOs is sterile, so the farmer is forced to buy fresh seeds every year. (Any 3)	(i). Some people think manipulating nature for our own benefit is wrong. (ii). Others say it is cruel to breed for example cows which die if you don't milk them. (iii). Some people say biotechnology interferes with nature.	2/6	He was able to provide one correct answer while the other two were wrong as he stated what people do and not ethical implications as the question asked for.

John got 34 marks out of 58 representing 67% from the biotechnology test he wrote. This showed that he had some content knowledge though he had a few problems with some success criteria in provided the answers to the questions which required him to either define or describe. These short falls are discussed in this section.

John faced a number of challenges with getting most of the questions right, let alone giving adequate answers to some questions, compared with James and Joseph. In question 1(a), for example, John struggled to accurately describe the advantages of hybrid maize. He mentioned that hybrid maize yields twice as much but did not specify the local varieties in Malawi for comparison. Thus, while the yield increase is a valid point, the lack of specificity about local varieties makes the answer incomplete as it lacks a basis for comparison. He also incorrectly stated that hybrid maize is resistant to herbicides. But this applies more correctly to genetically modified maize, not hybrid maize. In 1(b), John described general cross-pollination instead of artificial cross-pollination specific to maize. He failed to address the specific process of artificial cross-pollination used in producing hybrid maize.

In question 2(a), John mentioned bacteria, fungus, and moulds. Moulds are a type of fungus, so only two distinct microorganisms were correctly identified. In 2(b), he mentioned scones and local bread, which were considered the same, so cheese and bread were taken as correct. The answer was partially correct, reflecting a basic understanding of fermentation products. But he answered all parts of question 3 (that is, a, b and c) correctly, thus demonstrating a considerable measure of understanding of the concepts covered in these questions. He correctly and adequately answered all parts of question 4 (a, b and c), thus reflecting a solid grasp of the concepts in the question.

As for question 5, which asked respondents to name two proteins and two enzymes obtained by recombinant DNA technology, John correctly gave two examples of proteins. But both proteins John mentioned were not part of the MSCE curriculum as they are above the level of the learners. The enzymes he named are also incorrect; restriction enzyme is too broad while the enzyme alkaline factitase does not exist. In question 6, John failed to explain how recombinant DNA technology is used in pharmaceutical companies.

In question 7, John correctly identified Covid-19 as a disease with a bioengineered vaccine. However, he erred on HIV which he mentioned as a disease with a bioengineered vaccine when, in fact, there was yet no vaccine for HIV at the time the study was being carried out. In question 8(a), John listed three uses of transgenics. However, two uses were similar (and thus evaluated as one) while the third use was wrong. Thus, while the correct identification of the use of transgenics showed some understanding of their uses, the repetition itself as well as the wrong answer revealed shortfalls in content mastery. Answers to question 8(b), which asked the methods used in the production of transgenics, were correct, but the answer to question 8(c) was wrong due to the fact that John misunderstood the initial question. Instead of describing the process, that is, DNA microinjection, John simply defined the method. In the last question (question 9), John incorrectly described the ethical implications of biotechnology on society, highlighting lack of awareness of ethical issues in biotechnology.

John's performance showed some struggles in answering several questions accurately, indicating the lowest content knowledge among the three teachers. Although he provided some correct information on uses of transgenics and methods used in transgenic production, example of a disease with a bioengineered vaccine, methods used in the production of transgenics, John showed lack of knowledge of several fundamental concepts in biotechnology, such as advantages of hybrid maize, a description of the process of artificial cross pollination as it occurs in maize, examples of microorganisms used in industrial production, examples of proteins and enzymes, applications of recombinant DNA in pharmaceuticals, methods and processes of transgenics, and, finally, ethical issues in biotechnology.

Analysis of content knowledge of John based on outcome of interviews

This section presents analysis of content knowledge based on the semi-structured interviews which were conducted before and after the lessons and later transcribed.

An excerpt of the post-lesson interview with John

Researcher: From what you prepared, what were the key concepts that you wanted your learners to know?

John: The word Gene combination, and introduce biotechnology and even the importance of biotechnology and the concepts which goes with it and the lesson went as it was planned.

Researcher: What was the aim of the lesson?

John: Wanted to introduce what biotechnology is and the key concepts that are in that topic.

Researcher: What challenges did you observe or note during the lesson?

John: The new terms need to be taught again because the students seemed not to understand the terms such as biotechnology, recombinant and other terms. Most of these students are slow learners, you have to repeat and repeat so that they understand.

Researcher: Did you identify any misconceptions during the lesson?

John: Yes, Sir, one student asked me whether plants have genes or not. I was surprised that a student asked me that question. I think the students think that only animals have genes. In the next lesson, I will try to explain further about the presence of genes in plants because during the class I failed to explain to the student.

During the pre-lesson interview, John indicated that his first lesson would focus on animal and plant breeding before teaching genetic engineering, which would be his second lesson. John cited students' prior knowledge of plant and animal breeding from their previous agriculture lessons as one powerful resource he would capitalise on to effectively teach animal and plant breeding and enable students easily achieve the objectives of both the current lesson and the subsequent lesson that built from it. However, he specifically cited the newness of the topic and the fact that this was his first encounter with the topic as the challenges that would affect his delivery of the topic biotechnology.

The researcher gathered through the pre-lesson interview that John had not written a lesson plan for both lessons. The reason he gave for not having a lesson plan with him was a huge workload, that is, that he needed to teach 28 periods a week and, therefore, did not have time to develop lesson plans for each of the 28 lessons. The researcher also anticipated the lack of a written lesson plan for the lesson to be a challenge for him during the actual implementation of the lesson, although John did not acknowledge it as a weakness.

As regards his approach to the second lesson, John indicated that he would start the lesson by asking students questions about what he taught them in the previous lesson on animal and plant breeding. Then, he would finish the content that he left in the previous lesson before introducing the topic for the current lesson. Thereafter, he would introduce the topic for the second lesson.

The researcher noticed through the interview that John knew what he wanted to teach despite not having an outline of the content written down as provided in the syllabus. In fact, as the researcher gathered through the interview, John's school did not have a copy of the senior secondary biology syllabus. This forced John to solely rely on a biology textbook for planning.

During interview after the lesson, John believed the observed lessons went well overall. He admitted to being unprepared for a student question about plant genes. He acknowledged that while the content on plant and animal breeding seemed straightforward, students struggled to connect it with genetics and evolution. John mentioned that students had learned about hybridisation in Form 3 agriculture, implying an assumption that students should have retained and understood this prior knowledge.

John noted that the planned content for one lesson extended into two because his students were slow learners. This impacted his ability to cover the material as intended. This indicates a need for a more adaptive teaching approach to accommodate different learning paces.

John demonstrated some gaps in his understanding of biotechnology concepts such as genes, DNA, recombinant DNA, plasmid, and chromosomes. This was evident in both the lessons observed and the post-lesson interview. The lack of readiness to answer student questions highlighted gaps in his own understanding of the subject matter. His reliance on a single, erroneous textbook exacerbated these issues.

Findings on John's content knowledge based on observed lessons

This section presents the findings on content knowledge of John based on the two transcribed lessons. Appendix T shows part of the first transcribed lesson taught by John, and below is a summary of the themes from John's first transcribed lesson.

Themes identified through thematic analysis of John's first lesson

Content Knowledge

- Understanding biotechnology
- Introduces biotechnology as a combination of "bio" and "technology"
- He called biotechnology "recombinant DNA"
- **Hybridisation**
- This is a method described as a process of cross-breeding plants and animals used to improve new organisms which have desired characteristics.
- Explained the process of how genes can be introduced into another organism to improve a specific trait.
- **Advantages and disadvantages of hybridisation**
- Advantages provided by students included (a) Improved adaptability, (b) Development of desired traits, (c). Higher quality products
- Disadvantages included (a). Disease transmission (b). Need for specialised skills
- **The function of DNA in genetic engineering**
- He explains the structure and function of DNA in the nucleus
- He briefly described the process of altering DNA to improve an organism's characteristics

The lack of sequence in John's lesson delivery was also seen in the way he jumped about from one concept and then another without showing proper links and without showing transitions. For example, John began the first lesson by explaining the concept of hybridisation but quickly shifted to genetic engineering, then revisited basic genetics concepts (DNA, chromosomes). This lack of clear progression confused students, making it difficult for them to follow the lesson. He also spent an unusually huge amount of time revising genetic terms from previous lessons, which contributed to time management issues.

Another challenge John faced during lesson delivery was clear communication and interpretation of concepts. John struggled to clearly define and differentiate between hybridisation and genetic engineering. He introduced advanced concepts like gene recombinant, DNA code, and DNA transcription without proper context or clear definitions, adding to the confusion. He mentioned DNA transcription, which is beyond the secondary school curriculum and not appropriate for the MSCE level.

The researcher also observed several inconsistencies with student interaction. For instance, at some point, John initially asked students to define biotechnology terms but did not sustain this interaction throughout the lesson. He abruptly ended the lesson without allowing students to discuss the assigned questions, missing an opportunity for engagement and peer learning.

In addition to inconsistencies with student engagement, the researcher also observed frequent misalignment with the curriculum. He did not adhere strictly to the curriculum, as he failed to describe hybridisation as the curriculum demanded. He introduced complex concepts not included in the secondary school curriculum, such as DNA transcription. This extended to constant loss of focus on the success criteria of the lesson.

There were, however, some improvements in the second lesson. He managed to review the previous content and engaged students in pair work. He also structured revision very well, starting with a revision of the previous lesson and engaging students in pair work to discuss the advantages and disadvantages of hybridisation. Student engagement also fairly improved in the second lesson. He asked students to write down their answers on the chalkboard, facilitating better engagement and interaction. Finally, there was also marked improvement in clarification of concepts in the second lesson compared to the first lesson. For instance, he encouraged students to list advantages and disadvantages, aiding in a better understanding of hybridisation.

John correctly explained how hybridisation improves the adaptations of plants and animals to various conditions. He provided examples to illustrate adaptation improvements through gene introduction from one organism to another adapted to different environmental conditions. But he struggled to describe how genes could be complicated in an organism as a disadvantage of hybridisation. He also could not explain how hybridisation can easily transmit diseases. He simply accepted all the advantages and disadvantages listed by students without further critical analysis or correction.

John read a passage from a textbook that discussed genetically modified organisms (GMOs) and hybrids. He provided an example of *Bt.* Cotton produced in Malawi as a transgenic plant. He also highlighted the importance of biotechnology in improving yields and producing higher quality products.

John addressed student questions on cross-breeding plants, gene transfer in plants, and the presence of genes in plants. He further provided basic explanations, but these lacked depth and clarity in his responses. For example, with reference to cross-breeding plants, he explained cross-pollination but did not go into detailed methodology. Also, with reference to gene transfer, John mentioned the use of injectors, but did not elaborate on the specific techniques. Finally, he affirmed the presence of genes in plants, but did not explain the location or structure of genes in plants.

John's lesson showed some strengths in engaging students and attempting to discuss the content. However, a few challenges were observed in his ability to clearly communicate complex concepts and provide detailed explanations. For example, he could not describe the artificial cross pollination used in the production of hybrid crops. His reliance on reading from the textbook and accepting all student responses without critical evaluation also indicated a need for stronger content knowledge and instructional skills.

In summary, the lesson observations revealed some problems John faced with content mastery on biotechnology. As earlier highlighted, for example, he incorrectly equated biotechnology with recombinant DNA in his first lesson’s introduction. He also mislabelled the lesson topic "hybridisation" instead of "plant and animal breeding," which is the accurate term according to the syllabus. Furthermore, he incorrectly stated that maize varieties are improved by "gene recombinant" and mentioned "DNA transcription," which are advanced concepts not appropriate for the MSCE level and not included in student textbooks.

The way he handled students’ questions also demonstrated weaknesses in terms of his mastery of content of biotechnology. For example, when asked how cross-breeding is done, John provided a basic description of cross-pollination rather than a detailed process of artificial cross-breeding, showing limited content knowledge in this area. In the test, he provided the same response when he was asked to describe artificial cross pollination. Furthermore, students' pressing questions about gene transfer and gene locations in plants revealed that they did not fully grasp previously taught genetics concepts. John's brief and vague answers likely did not clarify these concepts for the students. Yet, despite these perceived weaknesses with content mastery, John managed to define hybridisation correctly as cross-breeding and provided mostly accurate examples, though he occasionally introduced incorrect or irrelevant information.

John's lessons lacked proper planning and structure, leading to a disorganised delivery of content. He did not thoroughly prepare to ensure that students understood the foundational concepts before introducing more complex ideas. His assumption that students were familiar with the content he was teaching likely contributed to the confusion observed during his lessons.

Findings and analysis of interviews and transcribed lessons on teaching strategies John used to teach biotechnology

This section presents the findings and analysis of the teaching strategies either used or described by John based on the interviews and the transcribed lessons.

In his pre-lesson interview, John indicated he planned to use question-and-answer technique to review previous lessons and assess students' prior knowledge. Thereafter, he intended to incorporate other collaborative learning methods to engage students in discussions and activities, such as discussions to foster understanding and demonstrations to visually explain concepts. He planned to give students opportunities to present their group work findings to the class. He planned to conclude each lesson with a question-and-answer session to assess student understanding.

John demonstrated a good grasp of subject-specific teaching strategies like question and answer, pair work, group work, and discussions. These methods are widely applicable across various topics and can effectively engage students in active learning. However, John lacked specificity in his approach to teaching particular concepts. For instance, he did not provide a clear strategy for teaching complex processes like genetic engineering, instead relying on textbook activities without further elaboration on how to make the content accessible and understandable.

During the actual lessons, John used the question-and-answer method in both lessons. In the first lesson, John used this technique to check students' prior knowledge about biotechnology. In the second lesson, he used it to assess the students’ understanding of the previous lesson. This method, thus, was effective in so far as it helped engage students at the beginning of the lesson and set a foundation for the new content both in the first and second lesson.

In the first lesson, John discussed the definition of biotechnology and thereafter switched to the lecture method using which he defined recombinant DNA and described hybridisation. He read from a textbook and explained the text to the students. Towards the end, John organised the students in groups and asked students to discuss the advantages and disadvantages of hybridisation. However, the lesson ended abruptly, and the group work was postponed to the next lesson due to lack of time.

During the second lesson, John instructed the students to go into their previously arranged groups and resume the discussions that were suspended during the previous lesson. Each group wrote their discussion points on the chalkboard, which were then discussed as a class, led by the teacher. Group work was effective as it facilitated collaborative learning, but the abrupt ending in the first lesson may have disrupted the flow and effectiveness of the activity.

John abruptly ended the first lesson without a proper conclusion or follow-up on group work. During the second lesson, John concluded by asking if students had questions, but he did not ask any questions himself to check for understanding.

John declared during the post-lesson interviews that all his two lessons went effectively well and according to plan. However, the researcher noticed during observation of the two lessons that John used fewer strategies than he initially planned and revealed during the pre-lesson interviews. Although he used pair work and question-and-answer, he did not ask the pairs to write on the chalkboard what they had discussed for further discussion by the class. The researcher also noticed that John frequently used the lecture method in both lessons, thus limiting students' participation.

Knowledge of teaching strategies as demonstrated in John's CoRe

This section describes and analyses the teaching strategies that the John wrote in his CoRe. These are the strategies which he proposed to use to teach biotechnology concepts. These teaching strategies were discussed separately because they covered the whole topic of biotechnology, unlike the previous section which used data from the pre-lesson interviews, lessons observed and post-lesson interviews only. These were summarised in a table 4.6.

John's CoRe spelt out three main teaching strategies (see Appendix O). He planned to use the lecture method address Big Idea A (covering the history of biotechnology), Big Idea B and Big Idea C. He also planned to use experiments and discussion on Big Idea D and to use debate to teach ethical implications of biotechnology appearing as Big Idea E. Table 4.6 summarises John's CoRe.

Table 4. 6: Summary of teaching strategies as demonstrated in John's CoRe

Big Science Ideas / Concepts	Teaching strategies
A. Historical outlook of biotechnology	Inform students when biotechnology started, knowledge of ancestors, and recent knowledge so that they understand the history
B. Plant and animal breeding	Discuss how local and exotic plants can be crossed Let students have local and exotic animals and cross them
C. Genetic engineering (from DNA to recombinant proteins)	Discuss how to isolate the gene. Discuss how the gene is inserted in a host and the final products of genetic engineering.
D. Biotechnological applications towards drugs and food production	Use a food sample for discussion on the application of biotechnology. Discuss in groups how biotechnology is applied to make drugs and food Doing experiments
E. Ethical implications of biotechnology	Debate on ethical implications, of the use of biotechnology.

During the pre-lesson interviews, John mentioned group work, pair work, discussion, and quizzes as the teaching strategies he would use during his lessons. He did use these strategies during the lessons, but he also used the lecture method on each of the Big Ideas although the lecture method was meant to be used on Big Idea A only as indicated both during the interview and in the CoRe.

Pair work was mainly used during John's first lesson, but group work dominated the second lesson. But the lecture method dominated all strategies in both lessons. At some points within the lesson, he read content to students directly from the book. He did not use any illustrations or concrete objects to either demonstrate a process or to describe a concept. John's excuse for adopting and overusing the lecture method was that if he often resorted to group work and pair work, then he would run out of time and thus not be able to cover adequate work with the students.

Findings on John's knowledge of students and awareness of learning difficulties

This section describes the knowledge the John had before teaching a specific concept or during the planning of a lesson. It presents results that address research question three: "What knowledge of students' conceptions and learning difficulties do biology teachers have about biotechnology?"

During interviews, John was able to provide insights into students' conceptions. John described his students' conceptions and learning difficulties related to biotechnology in their CoRes (Content Representations). The section outlines these conceptions and learning difficulties as described in his CoRe, classroom observations, and interviews.

In his CoRe, John listed some misconceptions students have about biotechnology (Appendix O). He stated, “Some students think that DNA is found in animals only and that products made from biotechnology, like food products, can easily cause diseases.” This was evidenced when a student asked during the first lesson, “Do plants have genes?” However, John did not provide prior knowledge that students might have related to different concepts in the topic, such as plant and animal breeding, genetic engineering, biotechnology applications, and ethical implications. During pre-interviews, he explained that students had already been taught about animal and plant breeding in Form Three Agriculture. John assumed that students were aware of and understood what he had taught the previous year.

John identified content-related difficulties, including the disadvantages of cross-breeding, genetic engineering, and other biotechnology applications. However, he did not mention the limitations he might face while teaching the topic.

Analysis of John’s responses in his CoRe and interviews showed that John had very limited knowledge of his students. He assumed that the students understood the material, yet in the classroom, students demonstrated difficulty understanding most biotechnology concepts, starting with plant and animal breeding, genetic engineering, and biotechnology applications.

Findings on John’s knowledge of assessment

This section presents the findings of John’s knowledge of assessment based on the interviews and his CoRe.

John did not present any assessment instruments during the pre-lesson interviews. He mentioned that he would rely on questions from the textbook during the lessons and explained that he did not write lesson plans due to his heavy workload. During the lessons, he rarely asked questions and did not allow students time to ask him questions. John indicated that he would prepare a summative assessment test after teaching the entire topic of biotechnology. However, he did not administer this test, citing an overwhelming amount of material to cover and the proximity of national examinations as reasons for skipping it. The researcher, nevertheless was interested in formative assessment as it could let the teacher know either the students had understood or not the content.

In his CoRe, John primarily described the questioning technique as his main formative assessment method. This technique was observed in all the lessons, used at both the beginning and end of each lesson. John also mentioned using experiments and case studies as assessment methods. Despite listing experiments as a potential assessment tool, he did not explain how he would implement them, as neither his textbook nor the syllabus provided experiments for biotechnology. Given that experiments were beyond the scope of the MSCE curriculum, they were not deemed necessary in this context.

Overall, while John demonstrated knowledge of assessment methods, he did not fully utilise them in the classroom, relying primarily on questioning techniques.

Findings on John's knowledge of biotechnology curriculum

This section presents the findings of John's knowledge of biotechnology curriculum based on the interviews and what he described in the CoRe.

John demonstrated limited knowledge of the biotechnology curriculum. He relied heavily on a single textbook, *Njolinjo (2014)*, and had little familiarity with other recommended resources or the syllabus. His understanding of the success criteria or objectives and specific content required by the curriculum was inadequate. For example, he struggled to explain the success criteria and did not effectively cover the intended objectives in his lessons.

John did not prepare lesson plans or notes and used only the textbook and chalk during lessons. He did not inform students of the success criteria for each lesson, making it unclear what students were expected to learn. Despite having access to other textbooks and resources, John preferred *Njolinjo (2014)*, which he believed was straightforward and error-free. However, analysis showed that this textbook had inaccuracies and did not fully cover all required content. For example, the textbook introduces the topic by stating that *"Biotechnology is also called recombinant DNA"* which is not correct. Recombinant DNA technology is what is also called genetic engineering.

In his lessons, John failed to cover specific curriculum requirements. For instance, he did not describe examples of animal breeding or provide clear explanations of genetic engineering processes. His teaching was limited to reading from the textbook and occasionally answering questions. When faced with questions not covered in the textbook, he was unable to provide adequate responses.

His introduction of advanced genetic concepts that are not part of the curriculum further indicates a misunderstanding of the appropriate content level for secondary school students. This indicates gaps in his understanding of the curriculum and appropriate content level for his students. It is also obvious that a lack of proper planning and preparation for the lesson, as evidenced by the absence of a lesson plan for each of the two lessons he delivered, contributed to problems relating to content knowledge and content mastery.

In his CoRe, John provided content to be covered in all five Big Ideas which he mostly developed by using a single textbook, ignoring other recommended textbooks and the syllabus (Appendix O). One of his stated objectives, which appeared in Big Idea Five, was for students to know the background of biotechnology. His other stated objective, appearing under Big Idea B, was for students to know how cross-breeding takes place in both plants and animals using crosses of indigenous and exotic species of both plants and animals. The goal was for students to know how hybrids are formed. However, he did not clearly describe what students were supposed to learn under Big Idea C. He only wrote *"How new genes are formed by modifying DNA of an organism to produce new genes with new characteristics*" as what students were to learn without describing the process of genetic engineering. He also did not give a reason why students must learn the process of genetic engineering.

But he described different applications of biotechnology under Big Idea D. Under this big idea, he planned to teach students treatments for different diseases such as cancer, heart attack, and anemia; how vaccines are produced that provide safe and effective immunity against diseases like Hepatitis B, and also the artificial production of proteins. In the last Big Idea, he planned to establish from among the students whether their culture can accept transgenics and how the community can be provided with civic education. He gave reasons for teaching the content under each of the Big Ideas, but the reasons did not align with the concepts.

Under the Big Idea E, John outlined some beliefs about biotechnology. He wrote the statement, “our culture can accept transgenics provided people are civic educated”. However, the syllabus stipulates that students must learn the benefits and problems associated with biotechnology. He did outline some of the problems and benefits of biotechnology, but he included one wrong point, which is, “cells can be taken from dead embryos”. He gave reasons why students must learn about ethics where he stated that “to know how the topic links with ethics and some people think manipulation of nature for human benefit is wrong”.

John’s CoRe showed that he had some basic content knowledge but lacked detailed understanding and alignment with the curriculum. His descriptions of what students should learn were vague and not fully aligned with the syllabus requirements. His explanations for each Big Idea were often general and did not include specific content or detailed reasons for teaching particular topics. For example, his description of genetic engineering was incomplete and lacked clarity.

John’s approach to teaching biotechnology was not well-aligned with the curriculum. His CoRe and lesson implementation showed gaps in his understanding of both the content and the pedagogical requirements. He struggled with preparing students for assessments and did not provide effective formative or summative evaluations.

John’s knowledge of the biotechnology curriculum and his ability to plan and implement lessons effectively were limited. His reliance on a single textbook and lack of detailed lesson preparation hindered his ability to cover the required content comprehensively. Additionally, his failure to communicate success criteria and address student questions impacted the effectiveness of his teaching. Improving his curriculum knowledge, lesson planning, and resource utilisation would enhance his ability to deliver the biotechnology curriculum more effectively.

5.3 Cross case comparison of content knowledge of the participant teachers

This section presents a cross case comparison of the content knowledge the teachers have based on the biotechnology test, semi-structured interviews, transcribed lessons and the CoRes each participant presented.

The study investigated the biology teachers' understanding of biotechnology using a biotechnology test (see Appendix G). The test results for each teacher were described and analysed separately. The results showed that Joseph scored 47 out of 58 (79%), James scored 52 out of 58 (90%) and John scored 34 out of 58 (67%). The analysis of the performance of the participants, question by question, revealed that each teacher faced problems with certain areas of the content of biotechnology. However, the test results provided a quantifiable measure of each teacher's understanding of the subject. While Joseph and James scored relatively high, indicating a good grasp of biotechnology concepts, John's lower score revealed more substantial gaps in knowledge.

On the production of hybrid maize concept, Joseph and James were able to provide correct production process while John only managed to describe simple cross pollination. John could not show his knowledge of artificial cross pollination. The microorganisms used in some applications of biotechnology include bacteria, algae, fungi and viruses. While Joseph mentioned all the correct microorganisms, James and John mentioned the group name, fungi and types of it as different microorganisms. This shows lack of prior knowledge on types of microorganisms. Some of the important concepts in biotechnology include genetic engineering, recombinant DNA, a clone and transgenic organisms. In the test, Joseph could not define recombinant DNA which the other study participants managed to define.

James demonstrated to have knowledge of some of the products of recombinant DNA technology by mentioning the enzymes and proteins produced which Joseph could not mention. However, John did not have this knowledge. Similarly, John managed to describe two uses of transgenic organisms which the other two participants described well. All of them missed one or two steps in the description of the method of producing transgenic organisms. The last success criteria in the syllabus demands that students should be able to describe ethical implications. Joseph and James were able to demonstrate that they have the knowledge of ethical implications on the society which John showed to lack the content on.

During the pre-lesson interviews, Joseph and John outlined similar key concepts they planned to teach. They planned to teach the meaning of biotechnology and plant and animal breeding in the first lesson, while James started with prior knowledge from the previous topic, genetics, variations so that he connects the prior knowledge to the new topic, biotechnology where he described the same content as Joseph and John. For the second lesson, Joseph's aim was to teach the students the process of genetic engineering. However, he stated that he would introduce the topic by revisiting what was covered in the first lesson and applications of biotechnology which he gave students as homework. However, James stated that he would introduce the second lesson by revisiting what he had taught in the first lesson and then teach the students genetic engineering. Unlike Joseph, James stated that he would teach applications of biotechnology as a third topic after he had taught genetic engineering. The case of John was different because he managed to teach part of the first success criteria, animal and plant breeding in the first lesson, he explained that he would continue from where he stopped before he could teach genetic engineering.

The post-lesson interview findings for Joseph's two lessons were similar because he stated that the lessons went on well as he had expected. The mistakes he made during the lessons were attributed to the textbook he was using. This excuse could have been avoided if he had used other reference sources such as SMASSE hand out of biotechnology which was provided during the 2018 SMASSE in-service training. James acknowledged that the illustrations and visual aids he used assisted the students to understand the content better under both plant and animal breeding and genetic engineering concepts. John, though, he stated that his lessons were good, he was able to acknowledge the mistakes he made in delivering the content especially where he could not provide clear explanations to the students. This showed lack of preparedness. By reading the textbook in front of students as he taught, it showed his lack of preparedness of the content to teach.

James proved to have some content knowledge, was well-prepared, and effectively communicated complex concepts. On the other hand, while James demonstrated a solid grasp of most biotechnology concepts, he could not clearly distinguish some concepts, such as plasmids and chromosomes. At some point, he also introduced concepts that were apparently beyond the level of MSCE learners, that is, concepts not prescribed in the initial MSCE biology curriculum.

John's frequent confusion of concepts and inability to give clear and accurate explanations of concepts obviously point to some problems with content knowledge and content mastery. His inability to correctly address student queries and his reliance on a faulty textbook demonstrate a lack of comprehensive content knowledge. Obviously, overreliance on a single textbook, which is itself flawed, contributed to these serious errors in as far as biotechnology is concerned.

5.4 Cross case comparison of the topic-specific teaching strategies

This section presents a cross case comparison of the topic-specific teaching strategies described in section 4.2.1.2, 4.2.2.2 and 4.2.3.2 based on interviews and observed lessons. This includes the analysis of the strategies the teachers had presented in the CoRes presented in sections 4.2.1.3, 4.2.2.3 and 4.2.3.4. The teaching strategies in the teaching of biotechnology fall into two categories, namely, subject-specific strategies and topic-specific strategies. According to the Consensus Model, topic-specific teaching strategies form one component of Topic Specific Pedagogical Content Knowledge (TSPCK). For this reason, TSPCK was examined separately to understand how the whole TSPCK was used by different participants in the study.

Teaching strategies ensure that content is delivered to students in an easy and effective manner, and in ways that ensure students understand the concepts taught. Teaching strategies, together with strategies for managing the classroom as well as lesson plan designing, form part of the pedagogical knowledge (Gess-Newsome, 2015). The purpose of this section, thus, is to describe the teaching strategies which each of the three participant teachers used in teaching biotechnology. In light of this, the section addresses the second research question, which is, “what topic-specific teaching strategies do biology teachers use in teaching biotechnology concepts?” Through this question, the researcher sought to find out how biology teachers present topic-specific teaching strategies on the biotechnology topic and how they were used. The section also reports on other knowledge bases that allow the teachers to build up their PCK.

The other components of TSPCK such as curricular saliency, knowledge of students' conceptions, and learning difficulties biology teachers have about biotechnology will be discussed as the researcher purports to answer research questions four and five.

Pre-lesson interviews were conducted with each participant to gather teaching strategies the teacher initially planned to use to teach the lesson. The participant was required to describe their teaching approach, stages and activities. Post-lesson interviews were conducted to offer the participant opportunity for self-assessment and self-reflection on how the teaching went on, that is, what went well with the lesson, what did not go according to plan and why.

During pre-lesson interviews, all participants indicated they would use familiar examples, context and analogies of commonly found materials to introduce their lessons. This was designed to provide students with a strong basis for understanding subsequent concepts of the topics. All three participants also indicated they would use illustrations in the form of diagrams printed on chart papers or drawn on the chalkboard to describe and illustrate abstract concepts and complex processes in biotechnology.

All participants used question-and-answer method, group and pair work and demonstration, although, admittedly, with varying degrees of effectiveness. They all indicated during the pre-lesson interviews that they would use these strategies to teach their lessons. During initial observation, the researcher observed that all participants began their lessons with a question-and-answer technique, which was either designed to assess what was learnt in the previous lesson or to probe students' prior knowledge of concepts that would be relevant to understanding the lesson to follow.

Joseph used the question-and-answer technique in the introductory part of his first and second lesson to engage students in the learning process, to evaluate their previous learning and to probe prior knowledge. He engaged group work to let students use the knowledge of a process of genetic engineering he had described before to devise a process of milk production in cattle. Unfortunately, the use of group work method was not effective as the students did not grasp the process of genetic engineering on the basis of which they were to derive a process of milk production primarily because Joseph used a lecture method and because he used sketchy and unclear diagrams to illustrate the process. Joseph lacked knowledge of topic-specific strategies, despite demonstrating strong command of subject-specific strategies. Thus, this demonstrates that the link between his content knowledge base and his teaching strategies knowledge base was weak.

James used some topic-specific teaching strategies as he taught plant and animal breeding and genetic engineering processes. He included the use of illustrations, organised group work around the recommended textbooks, allowed students to make presentations of the outcomes of their group discussions, and consolidated students understanding using clear illustrations. Through the use of these methods, James demonstrated sound knowledge of topic-specific teaching strategies. He demonstrated a strong link between his content knowledge base and his teaching strategies knowledge base.

John's use of group work was not effective. He used group work on an activity that simply required a question-and-answer technique since the activity was generally composed of recall questions (that is, Give advantages and disadvantages of hybridisation). James demonstrated knowledge of subject specific teaching strategies, although he failed to use them properly in some instances. He also demonstrated weak knowledge of topic specific teaching strategies.

Joseph and John primarily used the lecture method in explaining different concepts of biotechnology. This was a weakness as overuse of lecture methods of teaching quickly puts off students. Also, this demonstrated that the teachers were unprepared for their tasks and perhaps that they lacked ability to identify suitable and effective learner-centred topic-specific teaching strategies which could be easily linked to the content knowledge base they taught.

An analysis of the outcomes of the pre-lesson interviews, lesson observations and post-lesson interviews show that all three participant teachers generally used subject-specific teaching strategies. These subject-specific strategies included question and answer technique, group work and pair work. The topic-specific strategies of illustration appeared during James and Joseph's lessons.

James mentioned other subject-specific strategies in his CoRe, such as discussion, demonstration and brainstorming which are also stated in the syllabus, but he did not explain how he would use them during the lesson. Yet, one of the Prompts in the CoRe required the teacher to explain how he would use the strategies mentioned in the CoRe. In addition to not explaining how he would use the strategies appearing in the CoRe, James also did not use any of those strategies during his lesson. Other strategies James mentioned other strategies in his CoRe, such as think pair and share, discussion, field visit, use of resource person, explanations, brainstorming and debate, but none of these was used in either of his lessons.

In his CoRe, James explained how he was going to use think pair and share, discussion, field visit, use of resource person, explanations, brainstorming and debate during the lesson, but he did not provide justification for using each of these strategies.

As for John, he mentioned in his CoRe discussion, experiments and debate as the strategies he would use to deliver his lessons, but he only described what would be discussed and debated without mentioning the type of experiment he would carry out with the students. The use of experiments in this topic was not in line with what the curriculum demanded because the experiments in this topic are complex and require very expensive equipment and chemicals, hence experiments were not suggested or provided to be used in the teaching of the topic. This implies that John simply picked the strategy without a basis and awareness for doing so. The choice of an experiment as a teaching method may also be explained by his use of a textbook that gave wrong information about PCR, Njolinjo (2014). This error would have been avoided if John had used a teaching syllabus and a variety of recommended textbooks. In conclusion, both John and James lacked knowledge of the topic-specific teaching strategies for teaching biotechnology.

In conclusion, Joseph demonstrated content knowledge of the concepts he discussed in the two lessons, although he admittedly struggled to explain meaning of other concepts and give examples of those concepts. For example, he failed to give a clear and accurate definition of a plasmid and struggled to underscore a clear and correct distinction between a plasmid and a chromosome. This probably stemmed from inadequate preparation of the content he was to teach. Also, some steps of the process of genetic engineering which he described during the lesson were not found in any of the approved MSCE biology textbooks, and he even combined the first four steps into a single step, and this obviously confused the students who could not repeat the process.

5.5 Cross case comparison of teachers' knowledge of students and knowledge of learning

The findings from the CoRes, interviews, and observed lessons indicated that the teachers had knowledge of their students' biotechnology-related preconceptions. James was particularly notable for demonstrating this knowledge in his lesson plans and applying it in teaching various concepts. All the teachers showed awareness of these preconceptions through their CoRes and classroom interactions, often using question-and-answer techniques to probe students' understanding of previously taught biotechnology concepts.

Regarding the teachers' knowledge of their students' learning difficulties, all three participants described challenges related to the terminology of different concepts in biotechnology, with some difficulties originating from genetics, evolution, and reproduction. Joseph and John acknowledged that most of the students' learning difficulties were discovered through questions asked by students in the classroom and through peer teaching.

5.6 Cross case comparison of teachers' knowledge of assessment methods and techniques

This section describes the knowledge of assessment that biology teachers exhibited before, during, and after teaching the biotechnology topic. It seeks to answer research question four: "How do biology teachers assess students' knowledge and understanding of biotechnology concepts?" In the current curriculum, assessment serves as a tool for evaluating curriculum and instructional techniques as well as diagnosing, monitoring, and directing student learning (MoEST, 2013). Teachers are required to assess students as lessons progress to ensure comprehension. Assessments should periodically evaluate students' declarative or content knowledge, procedural knowledge, and conditional knowledge.

Declarative knowledge is the understanding of facts and relationships (Yilmaz & Yalcin, 2012). Procedural knowledge involves the procedures, processes, and skills necessary to perform tasks, requiring the execution of steps in a sequence to achieve a desired outcome. Conditional knowledge is the understanding of when and why to use declarative and procedural knowledge, necessitating critical thinking and problem-solving strategies (Yilmaz & Yalcin, 2012).

Before each lesson, the participating teachers were asked, “Have you prepared an assessment instrument to evaluate whether the aim of the lesson is achieved?” After the lesson, they were asked, “Will you do any follow-up assessment task on the content of this lesson? In what ways? What do you want to assess in this assessment task?” The sections that follow describe how each participant assessed their students and their responses to these interview questions before and after the lessons.

The findings revealed that the teachers had knowledge of assessment, including both formative and summative methods. They were familiar with various formative assessment examples, as outlined by the Ministry of Education, and were also aware of summative assessment practices. However, they predominantly used the question-and-answer technique as their primary method of formative assessment.

Regarding the biotechnology topic, none of the teachers had documented summative assessments. The only assessment records available were for mock examinations. There were no records of summative assessment results specific to the biotechnology topic or for other individual topics taught.

5.7 Cross case comparison of the participant teachers' use of the biotechnology curriculum

This section outlines the evidence provided by the teachers to demonstrate their knowledge of the biotechnology curriculum, including how they planned and implemented their lessons. Teachers were interviewed about their preparation and planning processes, including the reference materials they used. Classroom observations were conducted using a checklist as a supplementary instrument as the lessons were being recorded to analyse lesson implementation. This approach was aimed at addressing the fifth research question: "How do biology teachers use their biotechnology curriculum knowledge when planning and implementing biotechnology lessons?"

Curriculum planning and implementation were defined in this study as the process involving various activities and measures undertaken by teachers to use or organise documents such as the syllabus, recommended textbooks, and other supportive materials for teaching and learning in the classroom. Each participant was examined as a single case study to provide detailed insights into their approach.

Joseph used the syllabus and relied heavily on one textbook, *Njolinjo (2014),* for planning and implementing his lessons. His reliance on a single textbook, coupled with the absence of lesson plans, led to gaps in covering the full range of concepts required by the curriculum. His lack of comprehensive planning and diverse resources affected his ability to teach certain concepts effectively. Without detailed lesson plans, Joseph struggled to facilitate student participation and to address abstract concepts in biotechnology effectively.

James demonstrated effective use of the biotechnology curriculum. He utilised the syllabus, four different textbooks, and reference materials from SMASSE Inset. He developed detailed lesson plans, which supported his thorough and accurate delivery of the content in the classroom. James's well-organised planning and diverse resources enabled him to teach the intended content knowledge effectively. His approach ensured that students were exposed to a comprehensive understanding of biotechnology concepts.

John used only one textbook, *Njolinjo (2014)*, for both planning and implementation, neglecting the syllabus, which is crucial for guiding the curriculum content. His limited use of resources restricted the breadth of content covered, leading to gaps in curriculum alignment. In the classroom, John's reliance on a single textbook and lack of adherence to the syllabus resulted in the teaching of content that was not fully aligned with the required curriculum. This approach led to gaps in students' understanding of key biotechnology concepts.

The findings indicate that James demonstrated a thorough understanding and effective use of the biotechnology curriculum, resulting in well-structured and comprehensive lesson delivery. In contrast, Joseph and John faced challenges due to limited resources and inadequate planning. Joseph's use of a single textbook and lack of lesson planning affected his ability to cover all required concepts, while John's exclusive reliance on one textbook and disregard for the syllabus led to curriculum misalignment and incomplete content coverage. Improving resource utilisation and lesson planning is crucial for effective curriculum implementation and student understanding.

5.8 Findings on participants' Topic-Specific Pedagogical Content Knowledge (TSPCK)

The study aimed to understand how biology teachers utilise their knowledge bases in teaching biotechnology concepts, focusing on Topic-Specific Pedagogical Content Knowledge (TSPCK). TSPCK is the foundation by which knowledge of the subject matter of a particular topic, such as biotechnology, is transformed into a teachable content for students to understand easily (O'Brien, 2017). TSPCK involves transforming subject matter into teachable content and includes such components as Knowledge of Instructional Strategies, Content Representations, Curricular Saliency, and Students' Understanding and Teaching Difficulties. According to the framework used in this study, PCK is topic-specific and is thus called Topic-Specific Pedagogical Content Knowledge (TSPCK). The data from the teachers' CoRes, interviews, and lesson observations was analysed to evaluate these components.

During the pilot phase, participating teachers were asked to suggest Big Ideas for biotechnology topic. Joseph suggested as his Big Ideas the subtitles of the biotechnology topic appearing in the biology textbook by Msasa (2015) while James adapted as his Big Ideas the success criteria on biotechnology prescribed in the subject syllabus. John, on the other hand, proposed as his Big Ideas the success criteria on the topic of biotechnology appearing in the biology textbook by Njolinjo (2014).

Understanding the technical complexities involved with deriving Big Ideas for a topic, especially a topic such as biotechnology, the researcher engaged expert help of biology lecturers and an expert in development of CoRe. The researcher and the experts used the adapted biotechnology CoRe which Garritz and Velazquez (2009) developed for the Chilean curriculum, although the CoRe was slightly different from the one for the Malawi curriculum. The Big Ideas which the researcher developed with the assistance of the experts were then given to the three participating teachers to help them understand the topic and teach it effectively. The following was the template of the Big Ideas:

- Big Idea A – Historical outlook of Biotechnology
- Big Idea B – Plant and animal breeding
- Big Idea C – Genetic engineering, from DNA to recombinant proteins
- Big Idea D – Biotechnological applications towards drugs and food production
- Big Idea E – Ethics implications of biotechnology

Each participating teacher developed a CoRe based on this template (see appendices J, K and L). The CoRes which the teachers developed were improved with the help of the responses the teachers gave during interviews and using the lesson plans which James presented. The researcher also developed his own CoRe based on the same template, which he used to score the CoRes of the teachers. The researcher also used guidelines for scoring CoRes adapted from Mavhunga & Rollnick (2011) and Mphathiwa (2015) (Appendices N). The ratings were as follows; basic (1), limited (2), developing (3) and exemplary (4) for each component and the description of the guidelines for scoring was provided in chapter 3.

Table 4. 7: Results of scores of each participant on their CoRes

PCK Components	Participants			Total score
	Joseph	**James**	**John**	
Knowledge of teaching strategies	2	3	1	4
Curricular saliency	2	3	2	4
Content representation	2	3	2	4
What is difficult and what is easy (Knowledge of student understanding)	2	2	2	4
Student prior knowledge including misconceptions	2	2	3	4
Total	10(50%)	13(65%)	10(50%)	20

Analysis of Joseph's scores on TSPCK

Analysis of findings of the TSPCK components shows that Joseph scored 50% (Table 4.7). He scored an average mark on each component of TSPCK, showing that his TSPCK was average.

On teaching strategies, Joseph reflected awareness of the teaching strategies available to him to teach biotechnology effectively. He suggested various strategies he would use to teach biotechnology, but he gave no reasons to justify each of the strategies he mentioned. His CoRe also lacked a description of how he was going to use each of the strategies he mentioned. His CoRe showed that he would use questioning techniques, discussion, demonstration, and brainstorming.

Secondly, with reference to curricular saliency, Joseph developed content for all Big Ideas. But these simply appeared in summary form, lacking a vivid description of the content of the Big Ideas. He outlined success criteria for each Big Idea, but gave general reasons for teaching the Big Ideas. In as far as content representation is concerned, Joseph did not describe any illustrations or charts he would use to teach abstract concepts appearing across the Big Ideas.

As for knowledge of students' understanding, that is, what is easy and what is difficult, Joseph highlighted four areas in biotechnology he believed would be difficult for students to understand. He explained noted that it would be challenging for students and their communities to understand selective breeding as a biotechnology concept. He also noted that the abstract nature of most concepts in biotechnology would also pose challenges to students. This would include the use of models and drawings which would pose problems for students to understand what happens at a microscopic level without observing or seeing it. He also noted that it would be difficult for his students to accept the implications of biotechnology as most results of biotechnology applications are not instantly visible and take longer for their effects to be felt.

As for students' prior knowledge and misconceptions, Joseph highlighted students' misconceived knowledge of yeast as not being part of biotechnology. He also anticipated that some students would consider animal and plant breeding as a form of speciation. Joseph was unable to give clear details of misconceptions he expected students to have on concepts in biotechnology appearing in some Big Ideas.

In summary, Joseph's TSPCK in every component was average (that is, not beyond 50%). This affected his performance in teaching more abstract concepts such as genetic engineering.

Analysis of James' scores on TSPCK

Analysis of the TSPCK showed that James' score was higher than the other two participant teachers (65%). James' performance was impressive across the three components, namely, knowledge of teaching strategies, curricular saliency, and content representation, but his performance on the remaining two components was average.

On knowledge of teaching strategies, Joseph suggested teaching strategies he would use to teach biotechnology and gave reasons for selecting each strategy. For example, he explained that he would use think, pair and share to give students a chance to think first on their own before giving them the answer. He also stated that he would use discussion as a means to get students involved in the lesson. He indicated that he would use explanation as a means for either the students or the teacher to explain a concept or process like genetic engineering.

On curricular saliency, James outlined detailed content of what the students were to learn under each Big Idea. These included, for example, the impact of biotechnology in different disciplines and on everyday life. He gave reasons to enable students develop a positive scientific attitude, curiosity, and creativity under Big Idea C. These reasons were to assist the students in applying scientific, technological, indigenous, and non-indigenous knowledge to help them derive appropriate solutions to their problems.

On content representation, James identified the content he planned to teach and enriched it with explanatory notes and examples. He also outlined teaching procedures he would use and gave reasons for using the strategies under each idea. His lesson plans showed the textbooks and charts he planned to use during his lesson.

With reference to knowledge of student understanding, which is what is difficult and what is easy, James only described contextual constraints such as lack of teaching and learning materials, and his lack of expertise to handle experiments he noted were difficult. However, these are experiments he found in reference materials and not from the syllabus or recommended textbooks. James also faulted curriculum developers for not providing hands-on activities in the biotechnology curriculum. He noted that this weakness made the teaching of biotechnology concepts more theoretical despite the concepts themselves being abstract.

On students' prior knowledge and misconceptions, James stated that students did not take what people do locally in their communities such as brewing beer and bread-making activities as applications of biotechnology.

In summary, James' TSPCK was more developed compared to the other two teacher participants. He performed well in knowledge of teaching strategies, curricular saliency and content representations, giving clear explanations under each of these components of TSPCK.

Analysis of John's scores on TSPCK

John's overall score was 50%. He performed very well in students' prior knowledge and misconceptions, but his performance in content representation and what is difficult and what is easy was average. He got the least score under teaching strategies.

Under teaching strategies, John mentioned debate and experiment as the strategies he would use to teach concepts in biotechnology. He planned to use debate to teach ethical implications of biotechnology, which appeared under Big Idea E, whereas experiment would be used to teach abstract concepts appearing under the remaining Big Ideas. Unfortunately, the biotechnology curriculum did not recommend experiment as a strategy for teaching any of the concepts of biotechnology. Even John himself failed to explain how he would use experiment to teach biotechnology when the researcher asked him during a pre-lesson interview.

Under curriculum saliency, John provided the content which he planned to cover under all five Big Ideas. The content included the background of biotechnology, which he situated within the Big Idea A, and how cross-breeding takes place in both plants and animals using crosses of indigenous and exotic species of both plants and animals, which appeared under Big Idea B (i.e. this was meant to help students understand how hybrids are formed). However, the content he planned to teach students under Big Idea C was unclear, although he only gave a statement of the knowledge which he wanted the students to acquire (i.e. How new genes are formed by modifying DNA of an organism to produce new genes with new characteristics). He hardly described the process of genetic engineering as the curriculum demands and did not give reasons why students must learn the process of genetic engineering. In addition, John also did not present any illustrations or show how he would teach abstract concepts. Another shortfall of John’s CoRe was seen in the way he sequenced Big Ideas in relation to the concepts he planned to teach under each Big Idea. The researcher noticed that John wrongly situated some concepts within Big Ideas under which the concepts were not meant to be discussed. Also, the researcher noticed that some information John included in his plan were not part of the MSCE curriculum.

On content representation, John only managed to outline content he planned to teach without giving justifications for teaching it. He hardly showed awareness and knowledge of ideal activities or illustrations available to help him teach abstract concepts and processes in biotechnology in a manner that would be easily accessible to the students. He even failed to identify broad or specific topics within biotechnology that were problematic.

John’s knowledge of students’ understanding of concepts and processes in biotechnology was also weak. For example, with reference to the first Big Idea, he declared that he would require less time to teach plant and animal breeding because the students were already familiar with similar concepts from their form 3 Agriculture. He cited his being their teacher in their form 3 agriculture course as one factor that would strengthen the effectiveness of the lesson. During initial lesson observation, however, the researcher observed that students struggled to understand how artificial selection in plants is done, thus disproving the assumption John had that assumed that the students would easily grasp the concept because of their prior knowledge of similar concepts in Agriculture.

In his CoRe, too, John identified students’ prior knowledge and misconceptions in relation to biotechnology, but did not account for the consistent students’ knowledge. He mentioned that some students held as a belief that DNA is found in animals only and not in plants. This was proven true as, during the lesson, one student asked, “Do plants have genes and where are they found?” John identified further misconceptions in more than two Big Ideas, although he could not give the basis and reasons for the misconceptions.

In summary, the researcher evaluated John’s Topic-Specific Pedagogical Content Knowledge (TSPCK) for the teaching concepts in biotechnology as “developing” as he could not provide information and give reasons for each Big Idea. In some instances, he failed to present the content in logical order. John’s level of TSPCK might be explained by the fact that he does not attend Biology SMASSE INSET sessions and to his academic background.

Findings on analysis of content knowledge and TSPCK components in the recommended textbooks

This section describes the content knowledge found in the recommended textbooks of Biology. It also describes how the textbook writers have transformed the content into teachable content as well as the different components of TSPCK the textbooks might provide to ensure that students understand the content easily. These textbooks are those officially approved and certified by the Ministry of Education, Science and Technology (MoEST) through the Malawi Institute of Education (MIE) textbook evaluation and validation process.

Textbooks are pedagogical tools that provide support to teachers when choosing teaching strategies, assessments and other knowledge bases (Pavesic & Cankar, 2022). The assumption, thus, is that these approved textbooks, by virtue of their national approval and validation, are a reliable source of information for both teachers and students.

Currently, there are four approved textbooks for the MSCE biology subject. Teachers must decide which, among these four, is a reliable source of knowledge for their instruction. The textbooks are Avis, Barrett, Baxter, Dempster, Mhlanga and Ritchie (2018), Longman Strides in Biology, Student’s Book, Form 4; Nsasa (2017), Excel & Succeed Senior Secondary Biology Student’s Book. Form 4; Chimocha & Lungu (2017), Achievers Senior Secondary Biology, Student’s Book 4; and Njolinjo (2014), Arise with Biology, Students’ Book 4.

The researcher analysed these four biology textbooks to determine how they assisted teachers to acquire the right content knowledge and components of PCK. The writers who developed these textbooks used their content knowledge and PCK to transform topics into teachable materials (Mphathiwa, 2015). The textbooks were analysed in line with the components of the adapted consensus model of PCK, which are curricular saliency, specific teaching strategies, student pre-requisite knowledge, and content representation.

The topic ‘Biotechnology’ appears under different labels across the four textbooks. In Avis et al (2018), it appears as ‘Theme 7 Biotechnology’, while Msasa (2018) and Chimocha & Lungu (2017) labelled it ‘Topic 8 Biotechnology’. Njolinjo (2014) labeled it ‘Unit 8 Biotechnology’. The terms Theme and Topic are used interchangeably in the biology syllabus. Therefore, it is only Njolinjo (2014) who used Unit to represent a chapter.

As for the development, Nsasa (2018) and Chimocha & Lungu (2017) began by listing six success criteria as stated in the biology syllabus. Nsasa (2018) used a different statement than the one found in the syllabus, which Chimocha & Lungu states. Chimocha & Lungu introduces the success criteria with the phrase, “By the end of this topic, you must be able to:”, while Nsasa states, “After studying this topic, I should be able to:” Avis et al (2018) and Njolinjo (2014) did not list the success criteria.

Avis et al (2018) divided the whole chapter into topics by using the success criteria as the subtitles of the theme. The biology syllabus uses the terms Theme and Topic interchangeably while Avis et al (2018) take the term “Theme” to mean a broader chapter and a topic as a subset of the theme. Similarly, Njolinjo (2014) uses the success criteria as sub-topics in the chapter.

Chimocha and Lungu (2017) introduces biotechnology topic with a list of success criteria. They follow the list of success criteria with an introduction in which they defined biotechnology and briefly highlighted what is involved in biotechnology. The introduction is followed by the body which addresses each success criteria in detail.

In the first success criterion, Chimocha and Lungu (2017) discuss hybridisation using examples of organisms commonly found in Malawi. In the second success criterion, they highlight the applications of biotechnology in medicine, agriculture, and industrial applications. After this, they delve into the process of genetic engineering, under which they give a detailed description of the process of genetic engineering, explain how insulin is produced, and outline other applications of genetic engineering in plants and animals. In the last success criterion, they state the ethical implications of biotechnology. They merely list the implications without discussing them. This falls short of the requirement of the syllabus which states that, under this success criterion, the students should be able to discuss the ethical implications and not simply state or list them. Yet, even in their success criterion, Chimocha and Lungu (2017) stipulate that students should be able to list the ethical implications. They conclude the chapter with a summary of the main concepts in the topic followed by a unit review assessment. The entire chapter does not have illustrations or photographs. If these had been included, they would have helped simplify some abstract concepts and processes in the topic, making them easily accessible to students.

Nsasa (2017) opens the chapter on biotechnology with a list of success criteria. They follow this up with an introduction which highlighted a case story about a family that used to cultivate traditional breeds of maize, but later switched to hybrid maize. He develops from this case study a definition of biotechnology. In the first success criterion, Nsasa (2017) uses crops and animals commonly used or found in Malawi to illustrate the concept of hybridisation, although he doesn't clearly describe inbreeding and outbreeding. He then wraps the success criterion by giving students an activity which requires them to make field visits to designated sites where animal and plant breeding occurs.

In the second success criterion, Nsasa (2017) gives specific applications of biotechnology such as blood transfusion, plant and animal breeding using artificial selection, genetic counselling, Forensic science, and genetic engineering. In the third success criterion, Nsasa (2017) describes the process of genetic engineering and describes the application of biotechnology in medicine and agriculture. He builds from the discussion of the process of genetic engineering to describe insulin production and milk production. In the final success criterion, he discusses ethical issues in biotechnology followed by benefits and problems associated with biotechnology. He concludes the chapter with a summary of the content in statements form and a revision exercise. The whole chapter does not have any illustrations which can be used to simplify some of the abstract content.

Avis et al (2018) have a general overview of biotechnology which, among others, highlights the meaning of biotechnology. Unlike the rest of the writers, Avis et al (2018) treats each of the success criteria of Biotechnology as an individual topic. In Topic one, which Avis et al (2018) terms "Animal and Plant Breeding", they describe what is involved in animal and plant breeding, such as artificial selection, and proceeds to describe the hybridisation of plants, poultry, dairy cattle ending with an activity of just investigating how biotechnology can improve agriculture. In topic two, which they term "Applications of Biotechnology", Avis et al. (2018) combines two success criteria. They define genetic engineering, discuss the production of transgenic bacteria using a well-labelled diagram, discuss insulin production, genetically modified crops, and improving milk yield through genetic engineering.

Topic three appears with the title "Benefits and Problems associated with Genetic Engineering". The topic addresses two success criteria. Under this topic, Avis et al (2018) discuss the production of enzymes, hormones, and vaccines, followed by genetically modified crops. They then highlight concerns about genetic engineering and build from this discussion to describe ethical implications associated with using genetically modified organisms. The chapter concludes with a summary and a revision exercise.

Njolinjo (2014) does not outline success criteria for the topic at the onset. However, the success criteria appear within the body as headings of subtopics. He opens with an introduction in which he explains the meaning of biotechnology and outlines a brief historical background of biotechnology. Njolinjo's book is the only edition to include background information of biotechnology. In the introduction he wrongly called "Recombinant DNA as the other name for "Biotechnology". He follows up the introductory section with the first success criterion, treated under the subheading "examples of plant and animal breeding", under which he discusses how plant breeding is done. He errs by asserting that *Bt.* Cotton is a product of Lilongwe University of Agriculture and Natural Resources (LUANAR) when, in fact, it is a product of Monsanto Company and LUANAR is only credited with testing the efficacy of *Bt.* Cotton. Under the success criteria, Njolinjo lists different maize varieties grown in different countries, but does not explain in detail how artificial breeding is done. He concludes the section on animal and plant breeding with a description of both traditional and artificial methods of animal breeding.

The section on animal and plant breeding is followed by a discussion on applications of biotechnology. The discussion, appearing under the subheading “Applications of Biotechnology”, highlights different examples of applications of biotechnology and specifically mentions Polymerase Chain Reaction (PCR) as an application used in detecting cancer, genetic disorders, and viral infections. However, this concept is beyond MSCE level as it is covered in A-level Biology, mostly at tertiary level. The writer also provides illustrations such as cloning process using a sheep called Dolly.

The subtopic that follows, entitled process of genetic engineering, describes the process of genetic engineering with the aid of illustrations. The last subtopic, appearing under the heading ethical implications on the use of biotechnology, highlights arguments for and against therapeutic cloning in humans. He concludes the chapter with a review exercise.

Table 4. 8: Summary of the content knowledge in the recommended textbooks

Textbook	Content	Big Idea
Avis, J., Barrett, J., Baxter, F., Dempster, E., Mhlanga, A., Ritchie, E., (2018). Longman *Strides in Biology. Student's Book. Form 4.* Pearson Education Africa. Cape Town.	A brief introduction simply states that biotechnology has been used for thousands of years in agriculture, brewing, and making bread	Big Idea A Historical outlook of biotechnology
	Well-detailed content provides the process of producing hybrid seeds, with a representation of a maize plant's tassel, the production of poultry varieties, and the production of dairy cattle, including a representation of a dairy cow (p131), along with examples.	Big Idea B Plant and animal breeding
	He provides other different applications of genetic engineering by giving examples like the production of enzymes, hormones, and vaccines; the production of GMOs which are resistant to weedkillers and insect pests.	Big Idea C Biotechnological applications towards drugs and food production
	Defines genetic engineering and gives a detailed process of producing a transgenic bacterium with a detailed illustration or representation showing the stages of producing a transgenic bacterium. There are examples of GMOs presented such as golden rice that contains a gene	Big Idea D Genetic engineering from recombinant DNA to recombinant proteins

	that enables a person eating the rice to produce more vitamin A.	
	They provide different ethical implications and end with an activity discussing the ethics of GMOs.	Big Idea E Ethics implication of biotechnology
Nsasa, H. (2017). *Excel & Succeed Senior Secondary Biology Student's Book*. Form 4. Longhorn Publishers Ltd. Nairobi. Kenya	No content	Big Idea A Historical outlook of biotechnology
	Provides a list of different examples of maize varieties, new dairy breeds, and new poultry breeds without describing how the process of hybridisation takes place. The whole subtopic has no representations.	Big Idea B Plant and animal breeding
	He provides different applications of biotechnology which include blood transfusion, genetic counselling, and repeats plant and animal breeding using artificial selection, genetic engineering in medicine and in agriculture and forensic science. After genetic counselling, he gives an individual exercise of 2 questions and at the end of this sub-topic, he provides an activity that he calls a practice exercise 8.1 of questions, which could be an individual exercise also.	Big Idea C Biotechnological applications towards drugs and food production

	Starts by defining genetic engineering, followed by the aim of genetic engineering, and then the process of genetic engineering. He later describes the process using examples of human insulin production and milk production. However, in all these descriptions, there are no illustrations or representations of the processes.	Big Idea D Genetic engineering from recombinant DNA to recombinant proteins
	He starts this sub-topic by describing what is involved in ethical issues followed by benefits and problems associated with biotechnology. This sub-topic ends with an activity which is also an individual practice exercise.	Big Idea E Ethics implication of biotechnology
Chimocha, S., and Lungu, S. B. (2017). *Achievers Senior Secondary Biology. Student's Book 4.* East African Educational Publishers Ltd. Nairobi. Kenya.	No content	Big Idea A Historical outlook of biotechnology
	Provides selective breeding types, inbreeding, and outbreeding with examples of plant breeding, cattle, and pig breeding. On selective breeding, apart from inbreeding and outbreeding, he briefly describes genetic engineering and cloning as new methods of growing selected varieties of plants without the need for seed production. He ends with an activity which is also a field visit. It does not have any illustrations or representations.	Big Idea B Plant and animal breeding

	Briefly, he provides the applications of biotechnology in brief on medicine, agriculture, and industrial applications. There is no activity after this sub-topic and it does not have any illustrations or representations.	Big Idea C Biotechnological applications towards drugs and food production
	they start by describing genetic engineering and giving examples of where it is used before, they describe the process of genetic engineering using the example of insulin production. He also describes other applications of genetic engineering such as the production of transgenic goats, vaccines and continues further to discuss the benefits and problems of genetic engineering. This sub-topic too does not have any illustrations.	Big Idea D Genetic engineering from recombinant DNA to recombinant proteins
	This subtopic is also very brief as he simply listed down some ethical issues. This sub-topic too does not have illustrations also.	Big Idea E Ethics implication of biotechnology
Njolinjo, B. (2014). *Arise with Biology, Students' Book 4*. CLAIM Limited, Blantyre. Malawi.	Gives the year when recombinant DNA technology was first used, the 1970s.	Big Idea A Historical outlook of biotechnology

	Provides a separate heading, plant breeding with a list of examples of breeds produced as a result of either crossing or by either genetic engineering. He gives representations or illustrations of hybrids (p155) and another sub-topic of animal breeding which gives examples of poultry breeding and methods used. He also gives artificial breeding as another method for breeding cattle. However, he has some spelling errors and numbering problems in activities. He ends this sub-topic with an activity in which students have to develop a questionnaire they could use to obtain knowledge from breeders with the assistance of their teachers.	Big Idea B Plant and animal breeding
	He lists down different applications of biotechnology such as the production of hormones, insulin, proteins, herbicides, fresh-keeping tomatoes, safer vaccines, anti-cholera rice, DNA Probes where PCR is described briefly, and factor IX. He provides different illustrations for different applications and some of them are not very clear.	Big Idea C Biotechnological applications towards drugs and food production
	He starts by defining genetic engineering and later provides the steps used in genetic engineering with an	Big Idea D Genetic engineering from recombinant DNA to recombinant proteins

	illustration showing how it is done diagrammatically. Insulin production is used as an example and the cloning of animals. He ends this sub-topic with an activity of discussing how recombinant DNA on insulin has affected the lives of people.	Big Idea E Ethics implication of biotechnology
	He briefly gives some augments of some ethical issues and later asks students to do an activity in the form of a debate on the ethical implications of the use of biotechnology.	

TSPCK in the recommended textbooks

4.8.4.2.1 Curricular saliency

There were noticeable similarities among the four textbooks. All textbooks defined similar success criteria, although some textbooks treated the success criteria as standalone topics and others simply as subheadings of a topic. Furthermore, all textbooks contained definition of biotechnology and an overview of its significance to human beings. Avis et al. provide more details on each of the success criteria, followed by Nsasa (2018) and Chimocha & Lungu (2017). Njolinjo, on the other hand, contains a lot of serious factual errors and commits serous spelling errors despite including a bulk of content too. Njolinjo is the only one who provides in-depth information such as on Polymerase Chain Reaction (PCR) for students at the MSCE level.

5.8.1.1.2 *Content representation*

All the four textbooks address the objectives of the syllabus. But it is Avis et al. (2018) whose is content is broader and detailed compared to the rest of the textbooks. He includes detailed, adequate and clear photographs on plant and animal breeding as well as illustrations on stages of the genetic engineering process. Chimocha and Lungu (2017) and Nsasa (2018), on the other hand, do not have photographs and illustrations. This hampers students' ability to grasp and relate complex and abstract concepts such as genetic engineering.

5.8.1.1.3 *Students' prerequisite knowledge*

All the four textbooks lack a statement of how the new content, that is, biotechnology, relate to what students learnt in the previous topics. Nsasa (2018) tried to link concepts in biotechnology with concepts students earlier learnt through an individual activity by help of which he sought to introduce the discussion on applications of genetic engineering. The activity is based on hereditary disorders such as sickle cell anaemia, albinism and haemophilia, which are part of a discussion on genetic counselling under application of genetic engineering.

The participating teachers highlighted the prior knowledge their students possessed which they believed would assist them to easily understand concepts in biotechnology. They mentioned these sets of knowledge during interviews. Of all the three teachers, only James highlighted these sets of prior knowledge in his lesson plans.

5.8.1.1.4 *Topic-specific strategies*

There are more topic-specific teaching strategies in Avis et al. (2018) than in any of the textbooks which the researcher analysed. These include group work, pair work and homework. Nsasa (2018) and Njolinjo (2014) incorporate field work and exercises, but do not specify whether these are deigned to be carried in a group or by an individual student. Chimocha & Lungu (2014) have one fieldwork activity only.

Analysis reveals that only Avis et al. (2018) sufficiently supports teachers' PCK on content, although it fails to provide support other components such as pedagogical. All the four textbooks provide insufficient information on curricular saliency, content representation, students' pre-requisite knowledge, and topic-specific teaching strategies.

5.8.1.1.5 *Knowledge of assessment*

This section describes and analyses the assessments the textbooks provided to assist teachers and students determine the degree to which a concept or process has been understood before moving on to the next concept or process.

Avis et al. (2018) includes multiple forms of assessment throughout the chapter. For instance, students are asked to investigate local agricultural biotechnology efforts and report their findings in groups. After covering genetic engineering, students must discuss its classification as biotechnology, its role in food production, and create a flowchart depicting transgenic bacteria production in pairs. Furthermore, students engage in a group discussion on the ethics of GMOs before tackling revision questions at the chapter's end. These activities ensure ongoing assessment and comprehension checks throughout the learning process.

Chimotcha & Lungu (2017) provides a more limited form of assessment. Students are tasked with visiting a nearby plant and animal breeder to create and share a report with the class. Formal assessment is limited to a twelve-question revision exercise at the chapter's conclusion. This approach emphasises practical experience but lacks continuous assessment throughout the chapter.

Njolinjo (2014) takes a structured approach to assessment. Students develop a questionnaire for visits to plant and animal breeding facilities, with teacher assistance. They then discuss the impact of recombinant DNA insulin production on people's lives and engage in a debate on the ethical implications of biotechnology. The chapter concludes with a review exercise. This method ensures varied and interactive assessment opportunities.

Nsasa (2017) begins with comprehension questions based on a passage about a farmer's life, followed by an activity where students visit a research station to study biotechnology applications and impacts. Additional questions assess the students' understanding of genetic topics and their practical application. Students then differentiate between cross-breeding and inbreeding, explain gene therapy, and discuss the importance of genetic counselling. After covering biotechnology's benefits and issues, students describe its use in various fields and discuss ethical concerns before completing a revision exercise. This approach combines theoretical and practical assessments to ensure comprehensive understanding.

5.8.1.1.6 *Summary of analysis of recommended textbooks on the basis of knowledge bases*

All four textbooks featured similar content knowledge and followed the sequence of the syllabus subtopics, yet they varied in their coverage of different concepts. For example, Njolinjo (2014) offered more extensive content on biotechnology applications, including the functions of PCR, which surpass the MSCE level. Despite these differences, each textbook utilised subject-specific teaching strategies such as group work or individual assignments, except for Nsasa (2017). Unlike the other textbooks, Nsasa included questions assessing specific concepts.

A common characteristic among all four textbooks is the inclusion of revision exercises at the end of each chapter, serving as a means to assess students' understanding of the material. The activities provided in all the textbooks were similarly broad, effectively assessing the success criteria. This consistency ensures that students have multiple opportunities to demonstrate their comprehension and application of the concepts taught, regardless of the differences in the depth and scope of the content provided by each author.

Summary of findings on the research questions

Joseph demonstrated good knowledge of the syllabus's content, particularly in animal and plant breeding, genetic engineering, and ethical implications. But he struggled with anaerobic respiration of yeast and the relationship between a gene, DNA, and chromosome. He used familiar examples and context in lessons, but had ineffective group work and sketchy illustrations. He also relied heavily on lecture methods, showing a weak link between content knowledge and teaching strategies.

James answered almost all questions across all six success criteria, but missed viruses and embryonic stem cells. He demonstrated good knowledge despite not studying biotechnology at university. He improved his understanding through wide reading, recommended textbooks, SMASSE training, and handouts. Also, he effectively used topic-specific teaching strategies like illustrations and question-and-answer techniques and demonstrated a strong link between content knowledge and teaching strategies.

John struggled with most biotechnology concepts, including applications and genetic engineering processes. Of all the three participants, he is the only one with the lowest content knowledge among the three teachers. He primarily used lecture methods and failed to apply the SMASSE approach called Activity, Student-centred, Experiment, Improvisation/ Plan, Do, See, Improve (ASEI/PDSI) effectively. He also showed weak planning, making the content difficult to understand.

All three teachers used subject-specific strategies like group work and question-and-answer techniques. James demonstrated a broader range of strategies, including think-pair-share, discussion, field visits, and resource person use. All demonstrated awareness of students' preconceptions and learning difficulties, but lacked summative assessment results for biotechnology and demonstrated limited use of diverse teaching materials, with Joseph and John relying heavily on a single textbook.

All four textbooks followed the syllabus sequence but varied in concept coverage. Njolinjo provided extensive content on biotechnology applications, including PCR. Nsasa (2017) included specific concept-based questions, unlike the others. Each textbook utilised subject-specific strategies like group work and individual assignments. Nsasa, for example, uniquely assessed specific concepts through questions. All four textbooks included revision exercises at the end of chapters and activities that were broad, thereby effectively assessing success criteria.

5.9 Discussion of findings

The purpose of the present study was to investigate secondary school biology teachers' knowledge bases that affect their teaching of biotechnology concepts. This was influenced by empirical observation that every topic is affected by specific knowledge bases. In light of this primary purpose, the study was designed to answer the following five research questions:

1. How much content knowledge of biotechnology topic do biology teachers have?
2. What topic-specific teaching strategies do biology teachers use in teaching biotechnology concepts?
3. What knowledge of students' conceptions and learning difficulties do biology teachers have about biotechnology?
4. How do biology teachers assess students' knowledge and understanding of biotechnology concepts?
5. How do biology teachers use the biotechnology curriculum knowledge when planning and implementing the biotechnology lessons?

This section discusses the results presented in section 4.1. The discussion conforms to the similar order of the presentation of findings in section 4.1.

The discussion of findings in this section is organised into nine subsections based on the findings presented in the preceding section. Throughout the discussion, the results of the study will be linked to the theoretical framework and situated within literature. The discussion starts with the understanding of the content of biotechnology by the teacher followed by the topic-specific teaching strategies teachers used. This will proceed to a discussion of knowledge of students' conceptions and learning difficulties. The section also discusses teachers' assessment of students' knowledge and understanding of biotechnology and teachers' knowledge of the biotechnology curriculum. The section also discusses development of PCK and Teacher Professional Knowledge Bases and Topic-Specific Pedagogical Content Knowledge in the participants.

Analysis of findings on content knowledge of biotechnology

This section presents an analytical discussion of the findings of research question one which sought to investigate biology teachers' understanding of the content knowledge of biotechnology.

Based on analysis of outcomes of the biotechnology test, interviews, CoRes and lesson observations, James demonstrated strong content knowledge of biotechnology compared to John and Joseph. In fact, James edged both John and James in the biotechnology test and demonstrated during pre-lesson interviews that he knew very well the content he wanted to teach. During both lessons, too, James showed to have more content knowledge of biotechnology as he articulated abstract concepts and processes in biotechnology very well compared to the two participants.

James' content knowledge may, to a large extend, be attributed to his regular attendance of SMASSE In-Service Trainings and to his broader lesson preparations as highlighted in his tendency to gather and consolidate information from diverse sources. This is validated by empirical findings from research which justify that a teacher who regularly attend in-service capacity trainings become exposed to experiences, reflections and interactions by which their content knowledge and pedagogical experience expands (Mphathiwa, 2015). In fact, as findings of one study by Srutirupa and Muhalik (2013) indicated, a majority of biology teachers who report low content knowledge of a topic usually report not attending in-service trainings. In addition, proven evidence is also available to indicate that a teacher's high content knowledge is closely linked with a teacher's tendency to engage multiple sources of information about a given topic during lesson preparation (Zhao & Fan, 2022). This is even reinforced by the researcher's observation through interviews and document analysis that James, who consulted numerous sources, including all four recommended textbooks highlighted in this study, during preparation of his lessons, scored a higher mark on content knowledge. He also wrote an organised lesson plan and articulated abstract concepts and processes with depth and clarity.

Joseph, who was ranked second to James in terms of content knowledge, possessed fairly strong knowledge of the content of biotechnology as, occasionally, he gave students mistaken details. During pre-lesson interviews, Joseph articulated very well concepts he planned to teach, but failed to replicate this during the lesson. For example, during the lesson, Joseph gave wrong details about a plasmid, wrongly describing it as "a part in a bacterium specialised for multiplication". In fact, a plasmid is a small circular DNA strand in the cytoplasm of a bacterium or protozoan that can replicate independently of the chromosome and is used in the laboratory in the manipulation of genes (SMASSE, 2018). He did rightly describe a chromosome, however, as “where you will find DNA and in DNA is where you get a gene and so a gene is connected to the chromosome”. Joseph’s content knowledge was derived from his apparently inadequate preparation for the lesson especially on how the content should be delivered. This could be attributed to either lack of a lesson plan or the approach or the teaching strategies he used.

John ranked last in the tier of content knowledge. His performance in the biotechnology test was base. During pre-lesson interviews, he articulated the content he planned to teach. In class, however, the researcher observed that John struggled seriously to articulate concepts and processes in biotechnology. He read sentences and paragraphs straight from the book without giving further explanation or clarification of the content, thus demonstrating no mastery of the content he was communicating. He failed to use any of the teaching strategies he had mentioned in his CoRe, primarily sticking to the lecture method which was also characterised by a lot of reading of content from the book he was using to teach. Much of the information and details he gave were also wrong. For example, John failed to explain how recombinant DNA technology is used in pharmaceutical industries. He also failed to explain clearly the ethical implications of biotechnology. Furthermore, John used terminology which often confused students during the lesson. For example, he often used the term “injected” to describe how genes are transferred from one organism to another, a term that is not appropriate for this process and confuses students.

John’s knowledge deficiencies threatened the very potential of the students he taught to master and appreciate the significance of biotechnology. Teachers who nurse serious knowledge deficiencies are fond of giving inaccurate and often wrong details, and, by transferring this wrong and inaccurate knowledge to the students, they increase the deficiency of the students themselves (Käpylä et al., 2009). John's use of wrong and confusing terminology to describe concepts and processes in biotechnology may point to lack of adequate research during lesson preparation. A study by Borgerding, Sadler & Koroly (2013) found that a teacher's frequent use of terminology that is wrong and out-of-context usually point to the teacher's inadequate preparation, especially with view to research of vocabulary and background context related to the topic. John's weak content knowledge results from lack of adequate lesson preparation, both in terms of content to teach and teaching and assessment strategies.

John used one textbook only during preparation, and this adversely hinged on his content mastery. Findings of a study by Mthethwa-Kunene et al. (2015) revealed that a teacher's broad use of the biology curriculum during lesson planning and initial teaching, which is composed of the syllabus and recommended textbooks, ultimately influences a teacher's potential to master the content and is, therefore, a key determinant of the teacher's PCK. It has become a common trend among teachers in Malawi to use only a single source in preparing their lesson as a majority of teachers prefer to use textbooks that are only rich in content even if they contain no activities or assessments. Although his apparently points to a teacher's intimate value of content knowledge at the expense of the methods and approaches for communicating that knowledge to students, it smacks of serious pedagogical weaknesses that compromise the quality of learning as teaching strategies meaningly contribute to efficiency of learning. But this growing tendency to value books that only include content and place less value on assessments and teaching strategies is attributed to a trend that places more value on examination than on efficiency of learning (Sakala, 2013).

The general expectation was that all teachers would easily handle the first success criterion as the concepts covered under it were directly connected to those of the topic of genetics, which the teachers previously covered with the learners, and as the concepts were not as abstract as those covered under the other success criteria. The anticipation was thus that teachers would link this topic to genetics, which was previously taught and not abstract. The success criterion provided for students to mention examples of animal and plant breeding.

Joseph and John treated plant and animal breeding as a separate concept without linking it to genetics. The teaching of genetic engineering, which is more abstract in nature, would have been effective if teachers taught the process with the aid of illustrations or physical models to enable students grasp the concept easily. In addition, to make the process easily understood by students, teachers should have linked genetic engineering to genetics, emphasizing concepts like plasmid, chromosomes, genes, and DNA. They needed to remind students about plasmid, chromosomes, genes and DNA relationships before teaching them the process of genetic engineering as knowledge of these concepts greatly influence the ability of students to easily grasp the process of genetic engineering described using the example of insulin production. Doing this would have enabled students to also easily understand terms like recombinant DNA and transgenic organisms as well as the link that exists between them and genetics and biotechnology. The teachers should have noted that genetics and biotechnology are under the same core element.

Participant teachers reflected varying levels of content knowledge. The first factor influencing these varying levels of content knowledge is differences in academic background. Both Joseph and John are biology majors, with Joseph having a degree and John having a diploma. However, despite being biology majors, they both did not learn biotechnology in their pre-service education. They attended in-service training (SMASSE) in other subjects instead of biology. They used a single textbook (Njolinjo, 2014) and did not prepare lesson plans, indicating a lack of thorough preparation and content mastery. Their lack of lesson preparation led to reading directly from the textbook in class, showing low content knowledge without reference materials. They focused on content regurgitation without checking for student understanding.

Despite being unqualified, James demonstrated good content knowledge by attending biology SMASSE INSETs, reading multiple textbooks, and consistently planning his lessons with detailed lesson plans. He ensured he read widely, attended relevant training, and meticulously planned his lessons, which improved his teaching effectiveness and content delivery.

In summary, the differences in teaching effectiveness among the three teachers are attributed to their varying levels of content knowledge, preparation, and willingness to engage in continuous professional development. James's proactive approach to professional development and lesson planning allowed him to better deliver complex topics compared to Joseph and John.

Analysis of findings on topic-specific strategies used in the teaching of biotechnology

This section discusses findings on research question two. The purpose of research question two was to identify topic-specific teaching strategies biology teachers used in teaching biotechnology concepts as well as how the strategies were used by the teachers. The syllabus suggests the following teaching strategies which could be used in the teaching of biotechnology: - group work, explanations, demonstration and presentations (MoEST, 2013).

The researcher established through pre-lesson interviews that participant teachers were aware of both subject-specific and topic-specific teaching strategies. However, despite their awareness of various teaching strategies, the researcher observed during lessons that all teachers used the lecture method very much. This was despite the fact that the teachers never indicated they would use the method either during the interview or in their CoRe. During post-lesson interview, especially Joseph and John that indicated they were unable to vary their methods during the lesson, let alone use more learner-centred strategies, due to limited time. Teachers stated that the pressure of upcoming national examinations prevented them from using the recommended teaching strategies fully. Research shows that examination pressure influences the quality and amount of information teacher teach (Knippels, Waarlo & Boersma, 2005).

All participant teachers knew and mentioned question-and-answer, group work and pair work. However, there were other teaching strategies which only one participant knew and mentioned and the others did not. For example, in addition to the teaching strategies they all knew and mentioned, James mentioned and used peer teaching and observation which none of the two teachers mentioned or used. All these teaching strategies are in the syllabus. John, too, mentioned discussion and demonstration which neither James nor Joseph mentioned, although he hardly used any of them during the lesson. Joseph and John used the lecture method extensively during their lessons despite not mentioning the strategy during the pre-lesson interview.

The findings above indicate that all teachers were aware of subject-specific teaching strategies although they struggled to use them properly. These strategies, also called participatory methods, are suggested by the biology curriculum, and they are generally effective in facilitating active learning. Active or participatory learning is also called cooperative learning, and is touted as the most effective method in the teaching and learning of biotechnology (Hin et al., 2019). Cooperative learning occurs when students collaborate in small groups to work on tasks (Wahab, 2020). Therefore, on the basis of the pre-lesson interviews, the researcher concluded that all participants knew both subject-specific and topic-specific teaching strategies for teaching biotechnology.

Analysis of the Senior Secondary School biology syllabus shows that the syllabus prescribes a uniform set of teaching strategies for all topics, including biotechnology. These strategies (question and answer techniques, group work, pair work, and peer teaching) are intended to be flexible and adaptable. Despite this, teachers are expected to tailor these strategies to address specific challenges and enhance student comprehension of particular concepts.

Teachers have the option to use topic-specific strategies outlined in recommended textbooks. However, a study of the three teachers revealed that they often did not employ these strategies, citing time constraints as a major reason. For instance, Njolinjo (2014) and

Avis et al. (2018) provided topic-specific strategies that were not utilised by either teacher, who preferred more general methods due to time limitations, such as field visits. Furthermore, the textbooks recommended for teaching biotechnology, including those referenced by John and Joseph, were found lacking in representations such as diagrams and illustrations. These visual aids are crucial for helping students understand complex structures and processes. The absence of such representations in the textbooks posed a challenge for effective teaching and learning.

Joseph's approach in teaching concepts in biotechnology included using concrete objects, such as packets of different maize hybrid seeds, which served as a modelling strategy. This hands-on method allowed students to visualise and physically interact with the subject matter, enhancing their understanding of biotechnology concepts. Both Joseph and James employed illustrations and diagrams to explain biotechnology concepts. These visual aids helped students grasp the structures and processes involved in biotechnology more effectively than text alone. The use of visual representations can be considered a topic-specific strategy that complements the general teaching methods prescribed in the syllabus.

Joseph's introduction of the lesson involved engaging students with practical examples of maize hybrid varieties, which effectively connected theoretical concepts with real-world applications. In contrast, John’s approach was more direct, starting the lesson without assessing students' prior knowledge or using practical examples. This difference in introductory methods highlighted the impact of contextual and practical engagement on student understanding.

The unique teaching strategies which the researcher identified included the use of concrete objects such as packets of maize seeds, which can be described as modelling strategy, and the use of illustrations or diagrams used. These can be described as topic-specific strategies. James and Joseph used these topic-specific strategies, but John hardly used any topic-specific strategy.

All three teachers employed group work in their lessons, organizing students into mixed-ability groups which they had formed at the beginning of the term. Each group typically consisted of about eight students. This approach aimed to facilitate peer support, with weaker students receiving help from more capable peers. In their initial lessons, both John and Joseph used pair work to encourage brainstorming on specific concepts. This method allowed students to discuss and explore ideas before moving on to group activities. James also used group work but added a unique element by providing groups with different textbooks. Students were tasked with reading, discussing, and summarizing the content on genetic engineering. This approach encouraged active engagement with the material and collaborative learning.

The lecture method was the most commonly used strategy across all teachers, although it was not explicitly mentioned in interviews or CoRe (Content Representations) documents. The use of lectures varied in effectiveness, with notable differences in how the method supported or hindered student understanding. Joseph spent considerable time lecturing on genetic engineering, using insulin production as an example. Following the lecture, Joseph asked students to discuss how genetic engineering could enhance milk production in cattle. However, students struggled with this task because the initial lecture lacked proper illustrations or diagrams, leading to incomplete understanding of the processes involved.

James incorporated a lecture component but supplemented it with group work involving reading and summarizing from different textbooks. After group presentations, James created illustrations on chart paper to address gaps in student understanding. This approach, combining lecture with visual aids and interactive discussion, helped students better grasp the process of genetic engineering and its application to milk production.

Pair work, which was used by Joseph and John in the initial lessons to encourage brainstorming, was effective in engaging students early in the lesson but was often followed by a lecture, which sometimes undermined the benefits of initial group interactions. Lectures, on the other hand, can efficiently convey information, but their effectiveness is diminished without visual aids or interactive elements. For instance, on the basis of the lesson observation, Joseph's reliance on lecture without sufficient illustrations, like detailed diagram showing the process of genetic engineering, led to gaps in student understanding, while James's approach of combining lecture with visual aids and student presentations facilitated a deeper understanding of the topic. James's use of illustrations and diagrams after group work proved effective in reinforcing students' understanding of genetic engineering and its applications. This approach highlighted the importance of integrating visual representations with lectures to enhance comprehension.

John was observed reading passages from the textbook during lessons and asking students if they understood the material. This indicates a lack of preparation and reliance on textbook content without sufficient contextual understanding. Notably, John introduced Polymerase Chain Reaction (PCR) as part of genetic engineering, although the syllabus did not cover this topic. PCR was mentioned in the Njolinjo (2014) textbook but was not included in the official curriculum for MSCE level. John's mention of PCR without adequate explanation reflects inadequate lesson preparation and reliance on potentially misleading resources.

James noted in his interviews and CoRe that the curriculum did not include experiments for the biotechnology topic. This understanding led him to assume that every topic should involve practical experiments, demonstrating a gap in aligning with the actual syllabus requirements. James faced difficulty developing experiments due to the lack of guidance in the syllabus and textbooks. To address student difficulties and conceptual misconceptions, James employed creative methods such as peer teaching following group discussions. This approach aimed to make complex concepts more meaningful and accessible to students.

Despite following the same content sequence for topics like plant and animal breeding and genetic engineering, the depth of content delivery varied among the teachers. John covered content beyond the MSCE level, which was not aligned with the curriculum, while James and Joseph adhered more closely to the prescribed content. This discrepancy highlights how adherence to curriculum guidelines impacts the focus and depth of content coverage.

The analysis of the curriculum and recommended textbooks revealed that neither provided topic-specific teaching strategies that include practical work. This reflects a strict adherence to curriculum guidelines, which exclude practical experiments in biotechnology at the MSCE level due to their complexity. As a result, teachers were constrained to using the prescribed strategies without incorporating innovative methods.

Although the syllabus suggested the use of ICT, none of the teachers utilised or mentioned ICT tools in their lessons. This lack of integration might be due to teachers' unfamiliarity with ICT or the absence of necessary equipment. Bonde et al. (2014) argue that ICT tools, including virtual experiments and animations, can enhance students' understanding of abstract concepts in biotechnology, such as genetic engineering. Orhan & Sahin (2018) highlighted the positive effects of innovative teaching approaches, including virtual experiments, on students' laboratory experiences in biotechnology. These methods could compensate for the absence of physical experiments by providing interactive and visual representations of complex processes.

Despite its effectiveness, as noted by Salisu & Ransom (2014) and Hin et al. (2019), modelling was used by Joseph only. Modelling involves demonstrating new concepts through observation, which helps students understand abstract ideas by visualizing them in practice. The absence of modelling in teaching suggests a missed opportunity to facilitate deeper comprehension of biotechnology concepts. Modelling is tipped by Hin et al. (2019) to be one of the best teaching strategies due to its emphasis on construction and application of conceptual models of physical phenomena as a central aspect of learning and doing science.

The lecture method was predominant in all observed lessons. Teachers cited time constraints and the need to cover extensive content before national examinations (MSCE) as reasons for relying on lectures. This approach aligns with the transmission model of teaching, where knowledge is primarily delivered by the teacher, and students are expected to regurgitate information rather than engage in active learning.

All teachers expressed a desire to use more student-centred strategies but faced challenges due to exam pressures, lack of resources, and time constraints. Aydemir (2014) found similar results in studies on genetics teaching, indicating that examination requirements often influence teaching strategies, reinforcing a teacher-centred approach. The focus on preparing students for examinations led to a reliance on lecture and question-and-answer methods, reflecting a belief in the transmission model of teaching. This model prioritizes covering content over fostering deeper understanding and skills development, which may contribute to student disengagement and limited skill acquisition. Under this method, a student's ability is manifested through regurgitation of what has been learnt (Santrock, 2004). It is due to its inability to inspire effective learning and mastery of knowledge and skills that the lecture method is grossly discouraged (Johnson, 2010). Yet, the majority of teachers prefer to use the lecture method due to their familiarity with the method from their school and training days, and many teachers attest to its effectiveness as they used it to succeed in their school days (Mbati, Wanjala & Edome, 2020).

The lack of teaching aids, such as pictures or illustrations, compounded the reliance on lectures. Teachers without adequate resources may default to lecturing, which can lead to monotonous lessons and reduced student engagement (Malawi Institute of Education, 2004).

The key observation from analysis was that all the four currently recommended textbooks for teaching biotechnology lack topic-specific teaching strategies that could support effective instruction. Despite the curriculum suggesting the use of ICT, none of the textbooks included activities or strategies that leverage this tool to enhance students' understanding of abstract biotechnology concepts. This omission reflects a gap in aligning teaching resources with modern educational practices and technological advancements.

The most recent textbook, Avis et al. (2018), has not been revised since its publication. The lack of updates in textbooks suggests that they do not reflect contemporary teaching methods or technological tools that could enhance learning. Regular updates and revisions are necessary to incorporate new teaching strategies and align with current educational standards.

All the three teachers predominantly used the lecture method to cover extensive content quickly in preparation for examinations. While this method allowed for broad content delivery, it did not effectively address the abstract nature of biotechnology concepts or engage students in active learning. Despite mentioning various teaching strategies, such as ICT and modelling, the teachers did not implement these methods in their lessons. The reliance on lectures suggests a gap in employing diverse, topic-specific teaching strategies that could facilitate a deeper understanding of complex concepts.

Analysis of participant teachers’ knowledge of students’ conceptions and learning difficulties

This section discusses the extent to which biology teachers’ knowledge of students’ conceptions and learning difficulties influences their teaching of biotechnology concepts. According to the adapted consensus model, knowledge of students is both a teacher’s professional knowledge base and a topic-specific pedagogical content knowledge (see figure 2.5). Understanding students' prior knowledge, misconceptions, and learning difficulties is crucial for effective teaching, especially in complex subjects like biotechnology. The research aimed to assess how teachers' knowledge of these factors impacts their instructional strategies.

All teachers demonstrated awareness of their students' prior knowledge and potential misconceptions. They acknowledged that students were expected to have foundational knowledge of genes, chromosomes, and cell division from previous topics in reproduction and genetics. Despite their awareness, this knowledge did not consistently translate into effective teaching strategies. For example, Joseph and John were aware of their students' misconceptions but did not adapt their teaching methods to address these difficulties.

James used concrete examples, such as scissors and paper, to illustrate abstract concepts like the formation of recombinant DNA. This approach helped students grasp complex ideas more concretely. In contrast, Joseph and John did not use similar concrete representations, which may have hindered students' understanding of abstract biotechnology concepts.

Joseph was aware of specific misconceptions, such as the confusion between speciation and biotechnology, but failed to address these effectively in his teaching. For instance, he did not differentiate between speciation (from the Evolution topic) and the concept of plant and animal breeding within biotechnology, leading to continued student misunderstanding. Joseph's inability to effectively address misconceptions, despite recognising them, indicates a lack of preparation on how to teach these concepts effectively. His failure to connect plant and animal breeding to biotechnology, rather than speciation, highlights a gap in his instructional strategy and preparedness.

Data also revealed that James was aware of the prior knowledge his students possessed in relation to different concepts of biotechnology. He acknowledged this in his planning and preparation by developing illustrations and activities to assist him teach certain concepts in biotechnology effectively (VanDriel et al., 2014). James also provided more details on how he planned to handle the needs and diversity of his students than did Joseph and John. This showed that James, more than the other participants, was fully sensitive to the context and needs of his learners. He showed this through his knowledge of the impact of applications of biotechnology at the household level, so students could easily relate the concepts in biotechnology from a more familiar and local perspective to other less familiar perspectives.

John, though, demonstrated to have prior knowledge of his students and misconceptions he highlighted during pre-lesson interviews was not what came out during the lesson. John reported during the interview that he would move very quickly on the section of animal and plant breeding because the students already learnt about breeding in their form 3 agriculture. He assumed that the students would not have problems understanding the concept. The researcher observed that, after John had finished teaching animal and plant breeding, the students struggled to explain how hybridisation occurs. In the post-lesson interview, John attributed the failure of the students to explain how hybridisation takes place to not studying what they learnt in the past.

In his CoRe, John also highlighted the misconceptions he anticipated his students to have about biotechnology. This showed that the three participant teachers knew their students very well. A teacher’s knowledge of their students is critical as, based on findings of a study by Lucero, Delgado and Green (2019), allowing teachers to describe their own students’ thoughts can provide a richer understanding of student thoughts, especially since teachers have unique knowledge about their students.

All three teachers also predicted areas in biotechnology they anticipated to be difficult for their students. Joseph specifically highlighted the process of genetic engineering as the area which he believed his students would struggle to understand as it is abstract and can hardly be observed in real life. James, on the other hand, pointed out that a lack of experiments on any of the concepts of biotechnology was in itself a challenge to the students' chances of easily understanding concepts in the topic.

The researcher's assessment of these anticipated difficulties was that the teachers lacked innovation and critical reflection of ways and methods that could be used to simplify abstract concepts and make them accessible to their students. Although the teachers demonstrated awareness of the pre-requisite knowledge of the concept, they lacked innovation of how to teach the concept in a manner that would enable their learners easily understand it. This showed that the teachers lacked PCK.

Analysis of participant teachers' knowledge of assessment and understanding of biotechnology concepts

The current curriculum uses assessment as a tool for instruction and for evaluating, diagnosing, monitoring and directing student learning (MoEST, 2013). In light of this, every teacher is expected to assess the progress their students regularly and use the feedback to improve learning and maximise achievement. Teachers are required to assess declarative or content knowledge, procedural knowledge, and conditional knowledge.

The study observed that participants primarily used question-and-answer techniques to assess their students. The questions composing the assessment were often of a low order and, therefore, not providing a firm basis for making decisions about teaching and learning. The teachers assumed that the question-and-answer form of assessment was the most reliable method of checking students' mastery of learned concepts. The way the questions were designed forced learners to memorise learned content to be able to answer them, rather than to apply critical and analytical thinking.

Another very important observation the study made was the absence of a record of continuous assessment of theory and practical concepts. The researcher discovered that the teachers had not administered continuous assessments throughout all academic terms. By doing this, the teachers showed they did not adhere to the demands and principles of the curriculum. When asked why they did not administer continuous assessments and keep records as required, the teachers pointed out that their goal was to finish the syllabus and prepare the students for the national examination. Thus, they feared preparing and administering regular assessment and giving feedback would consume the limited time they had. The absence of regular assessment of work covered was a serious weakness in as far as effective instruction is concerned as it deprived the students of the feedback that would have improved their learning and blinded the teachers from gaps in the students' learning (Hong Kong Examinations and Assessment Authority, 2015).

All teachers, however, demonstrated awareness of both formative and summative assessments principles for the subject. They knew that the Ministry of Education policy provided that the final grade of a subject in a term consist of 20% continuous assessment and 80% end of term examination. The lack of teachers' adherence to assessment principles as stipulated in the MoEST assessment guidelines confirm findings of a study by Chiyombo & Nithyanantham (2023) which concluded that the lack of regular and detailed assessment of learners by many biology teachers stems from the fact that teachers in secondary schools in Malawi assessed students to pass public examinations and not to assist students acquire skills to deal with everyday challenges.

Analysis of biology participant teachers' use of the biotechnology curriculum

This subsection discusses the data teachers provided about how they planned and implemented their lessons on biotechnology. The discussion addresses the fifth question for this study, which is, "*"How do biology teachers use the biotechnology curriculum knowledge when planning and implementing the biotechnology lessons?"* The researcher interviewed the teachers to gather information on how they prepared and planned their lessons, as well as the reference materials they used during preparation. The researcher used an observation checklist to analyse how the teachers implemented the lessons they planned.

The researcher observed that Joseph and John overly relied one textbook in their planning and implementation of biotechnology lessons. It was only James who varied his resources during both lesson preparation and implementation. He used approved textbooks, the syllabus and materials he obtained from the SMASSE in-service trainings he attended. His lesson plans highlighted clearly what he planned to teach and how teach it. During initial teaching, the researcher also observed that James followed his lesson plan very well. Joseph, on the other hand, used only one approved textbook by Njolinjo and the syllabus. When asked why he opted for only a single textbook and the syllabus as his primary sources of information during lesson planning and implementation, he cited that he identified errors in the other textbooks. However, this is not true as the researcher found no errors in the way Msasa (2018) and Avis et al. (2018) presented concepts in biotechnology.

The use of a single textbook during planning and implementation of lessons may lead to the use of erroneous success criteria. A very good example of this scenario was observed with John who used only a single textbook in planning his lessons on biotechnology.

Instead of using the correct success criterion, "*Students must be able to describe the process of genetic engineering*," he devised his own success criterion which he stated, "*How new genes are formed by modifying DNA of an organism to produce new genes with new characteristics*." The other danger associated with using only a single textbook for lesson planning is that a teacher may end up planning a lesson whose content is either shallow or above the level of the class.

During lesson observation, the researcher noticed that teachers who did not develop a lesson plan and who admitted having only used a single source of information often made mistakes, gave explanations that lacked clarity, and struggled to answer questions students asked them. For example, one student asked John the question, "How are genes transferred in Plants?", and John's answer, "They are injected just like with an injection", demonstrated that he did not know how to respond to the question.

John and Joseph used declarative knowledge to describe the concepts in biotechnology. They extracted the definition of terms straight from the single textbook they used during their preparation. James, however, used both declarative knowledge and procedural knowledge as he had adapted his content from both textbooks and the syllabus. He did not use conditional content knowledge, however, as the questions he developed for his students were not high-order questions. But he varied his teaching strategies very well during the lesson, and this ensured that learners remained engaged throughout the lesson.

As for use of textbooks during the lesson, James used five textbooks in class which he distributed to the five groups which he organised during the lesson. The inadequate number of textbooks against the student population meant that individual reading assignments were not possible. James and John's schools also had textbooks available for students to use. But they admitted that they did not include use of textbooks in their lesson plans and thus did not bring additional textbooks to class.

How participant teachers developed TSPCK for teaching concepts in biotechnology

The researcher analysed transcribed lessons, post-lesson interviews and lesson plans to establish how participants developed TSPCK in the teaching of biotechnology. The researcher established through analysis of the data gathered from these instruments that participants developed TSPCK in biotechnology through recommended textbooks and other reference materials. The researcher also established through the analysis that the teachers possessed limited TSPCK. The components of TSPCK which the researcher identified included specific content knowledge, teaching strategies, content representation, and students' prior knowledge. The teachers did not demonstrate capacity in such components of TSPCK as topic-specific teaching strategies, content representations (illustrations), and how to use students' prior knowledge. The researcher expected the teachers to build on what the students already knew from genetics, reproduction and evolution as they teach more advanced concepts under biotechnology.

James demonstrated high content knowledge of biotechnology compared to John and Joseph. James cited a SMASSE In-service training which he attended in 2018 as the primary source of the content knowledge and teaching strategies he had. With the help of the content knowledge and awareness of teaching methodologies, James planned a detailed and logical lesson plan and derived impressive representations to use during the lesson. He also correctly identified the pre-requisite knowledge that would assist his students to easily grasp the concepts. He indicated that in his introduction of biotechnology, he would *"start by showing the students products of biotechnology so that students develop an interest in the topic before defining biotechnology and the basic concepts which made the students think that the topic is difficult."*

Joseph and John did not specifically attend the Biology SMASSE In-service training on biotechnology, but the researcher expected them to transfer and apply the knowledge of PCK they gained from Chemistry and Mathematics SMASSE INSET as SMASSE. This is because the teaching methods and approaches in Mathematics and Chemistry are similar to those used in Biology. For example, SMASSE emphasises an approach called ASEI (that is, an acronym that stands for Activity, Student-centred, Experiment and Improvisation) across all sciences. But they struggled with using and varying teaching strategies, especially with engaging student-centred teaching strategies. The researcher noticed that their lack of knowledge of content was primarily due to the use of a single source during their planning and preparation.

The researcher observed that, during the lesson, Joseph used sketchy illustrations that were specific to the topic, and James used more detailed illustrations compared to Joseph (Figure 4.1). John used group work once during the discussion of the advantages and disadvantages of plant and animal breeding. This, too, was a topic-specific strategy. However, the task for which he assigned students to perform in groups would have worked better if it had been assigned to individual students, as the students were already familiar with the concept from their previous discussions in Agriculture.

During interviews, all teachers asserted that they had changed their teaching approach from being predominantly teacher-centred to being student-centred. This, they contended, encouraged students to participate during lessons by, for example, asking for clarification where they did not understand. However, during the lessons, the researcher observed that Joseph and John used the lecture method more than any other method, thereby confirming findings of a study by Sakala (2013) which found that the lecture method is the most commonly used method in secondary schools.

When asked why they resorted to more teacher-centred methods of teaching, the teachers indicated inadequate teaching and learning resources, high classroom population, and the pressure to cover and complete the curriculum ahead of the national examination as the factors influencing their preeminent use of teacher-centred methods. James was the only teacher whom the researcher observed used student-centred methods well, thus manifesting higher TSPCK. As the researcher gathered, James' ability to use student-centred methods well during lessons stemmed from his regular attendance of SMASSE In-service trainings. Therefore, the study concluded that James had a more developed TSPCK compared to Joseph and John who had a limited TSPCK respectively about the teaching of biotechnology.

Teacher-professional knowledge bases (TPKB)

All participants possessed general pedagogical knowledge as they were all experienced teachers and had gone through the teacher education program. As the findings showed, there was close collaboration between components of the TPKB and TSPCK, thus making it difficult to separate them. It was also challenging to determine which level influenced the other as the adapted Consensus Model shows double arrows (see Figure 2.5). The implication here is that expanding one knowledge base may contribute to expanding another's knowledge base (Gess-Newsome, 2015).

The teachers' content knowledge of biotechnology enabled them to acquire more specific content knowledge of biotechnology such as, "How to teach genetic engineering". The teachers possessed prior knowledge of their students which assisted them to correctly identify areas in biotechnology which would be difficult to students and devise topic-specific teaching strategies to assist them to teach these difficult areas in ways that would make them accessible to students.

The adapted consensus model that has been used in this study encompassed TPKB which includes components such as knowledges of content, curriculum, assessment, pedagogical, and students. Some of these components of TPKB were easily identified in the course of the study than others. The next section discusses how some of the knowledge bases were identified during the study.

Biotechnology content knowledge

Content knowledge, according to this study, included all the rules, structures, and methods used to generate knowledge in the area to be taught such as biotechnology (Gess-Newsome, 2015). The theoretical framework for this study situated content knowledge within both TPKB and TSPCK (see figure 2.5). The findings of the study showed that the participant teachers possessed varying levels of content knowledge of biotechnology, as well as knowledge of other concepts in biology such as genetics and reproduction which fairly strengthened their ability to teach biotechnology. All of them were able to describe plant and animal breeding and partly genetic engineering. In addition, all teachers enough professional experience, having taught biology for no less than five years. It was for this reason that content knowledge was placed within both TPKB and TSPCK.

The teachers demonstrated strong content knowledge of biotechnology in their CoRes, although the level of knowledge they reflected varied across the Big Ideas. During lesson observation, the researcher noticed that teachers had less problems handling the content of five success criteria, but struggled with handling the sixth success criterion which required them to describe the ethical implications biotechnology. The struggles the teachers faced with this section of biotechnology may have resulted from the fact that the teachers did not learn biotechnology as a topic both during their secondary school days and during their initial teacher training at college. Also, as in the case of John and Joseph, they did not attend the SMASSE in-service training that covered biotechnology.

Pedagogical knowledge

Pedagogical knowledge is a component of Teacher Professional Knowledge Base. According to Baumert et al (2010) and Gess-Newsome (2015), pedagogical knowledge encompasses all strategies teachers use for classroom management and student engagement. Thus, pedagogical knowledge influenced both pedagogical content knowledge and topic-specific pedagogical content knowledge.

The results of the interviews, lesson observations and lesson plans showed that all teachers possessed pedagogical knowledge. The researcher observed that the teachers gained pedagogical knowledge through the experience they had accumulated over the years of teaching Biology. All teachers demonstrated some level of mastery of classroom management, which is one of the components of pedagogical knowledge. Their classes were marked by a certain level of discipline and organisation, although time management was the major challenge to all teachers.

Knowledge of assessment

Knowledge of assessment encompasses the design and implementation of formative and summative assessments as well as the utilisation of assessment results to inform educational planning and modification (Gess-Newsome, 2015). During pre-lesson interviews, all teachers explained how they would assess the students. During lessons, the teachers did implement assessment, but the assessments were primarily formative and composed largely of low-order questions. The researcher observed that the assessments were implemented at the beginning of the lesson, to assess previous knowledge tangential to the current lesson or to evaluate level of achievement of concepts covered in the previous lesson, and at the end of the lesson, to evaluate the current lesson. there was no summative assessment. When asked why they did not give a summative assessment at the end of the topic, all teachers cited lack of adequate time to prepare and administer a summative test as the reason.

Knowledge of students

Knowledge of students describes the teachers' awareness of their students' challenges, misunderstandings and prior knowledge that hinge on the ability of the students to learn and understand a given topic (Shulman, 1987; Aydin, 2014). On the theoretical model of this model (see figure 2.5), this knowledge is found in both the TPKB and TSPCK. Thus, knowledge of students is a component which influences both PCK and TSPCK.

The researcher established through interviews, lesson observations and document analysis that the teachers were aware of the students' prior knowledge that was tangential to the learning of biotechnology as well as the misconceptions students nursed about biotechnology. The teachers explained what their students about different subtopics of biotechnology. James, for example, produced lesson plans which highlighted the prior knowledge his students possessed. He prepared illustrations and activities that built on the prior knowledge of his students to make his lesson effective.

Knowledge of the biotechnology curriculum

Knowledge of curriculum encompasses knowledge of programs, resources and instructional materials designed for teaching specific topics (Shulman, 1986). It is held as one of the knowledge bases within the TPKB. During interviews, teachers identified the core elements of the biology curriculum and identified the topics that fall under each core element. The teachers also knew when biotechnology was to be taught within the academic calendar.

Joseph and John had problems with some aspects of the biotechnology curriculum, however. The researcher observed this lack of adequate knowledge of the biotechnology curriculum to their sole use of a single textbook. James, on the other hand, described many aspects of the biotechnology curriculum very well as he used a variety of sources in addition to the syllabus and the recommended textbooks.

Knowledge of self

Another knowledge base which the researcher identified in the participant teachers was knowledge of the self which, according to Turner-Bisset (1999), is held as an important requisite for reflection. It is the knowledge base every teacher must strive to possess if they aspire to improve their teaching. Knowledge of self is placed at the same level is placed at the same level as the rest of the knowledge bases of TPKB (Gess-Newsome, 2015).

One teacher who demonstrated knowledge of the self very well is James. James reflected high level of knowledge of self during the interviews the researcher conducted with him. He often referred to his educational background during discussions related to content knowledge. He cited his underqualification as the reason to read more to gain more knowledge of the content. His focus on gaining more content knowledge made him the best teacher as his lessons reflected rich knowledge of content and were more organised compared to lessons taught by John and Joseph.

John and Joseph also hinted about the importance of knowing one's level of knowledge of concepts before teaching a lesson. They reflected on the lessons they taught, but they could not admit or correct the mistakes related to content which they made in the course of their teaching. Some of the mistakes they made in the previous lesson continued to reflect in the following lesson, thus somehow indicating that they lacked knowledge of self which they should have factored in their planning and preparation.

Topic-specific pedagogical content knowledge

The theoretical framework which this study used was adapted from the Consensus Model (Gess-Newsome, 2015). The adapted theoretical framework made two fundamental assumptions, firstly, that Teacher Professional Knowledge Bases influence and are influenced by Topic-Specific Pedagogical Content Knowledge and that, secondly, Topic-Specific Pedagogical Knowledge influences and is influenced by classroom practices. Classroom practice was context-specific as each participating teacher was observed separately and treated as a single case study. The adapted framework excluded amplifiers and filters such as teacher beliefs to enable the researcher concentrate on TPKB, TSPCK and classroom practice. The researcher included classroom practice because the classroom is the context in which PCK and TSPCK components can be observed.

Comparison of knowledges among the study participants

The study has so far revealed knowledge bases which the three teachers reflected in their practice as well as the different levels in which the knowledge bases were reflected. As can be seen from preceding discussions, the three teachers demonstrated certain levels of content knowledge, knowledge of the curriculum, knowledge of self, pedagogical knowledge, knowledge of students, pedagogical knowledge and knowledge of assessment and TSPCK.

As far as knowledge of the curriculum is concerned, James demonstrated a higher awareness of the curriculum, marked by his ability to vary sources of information and to correctly spell the success criteria for each lesson he planned to teach. John and Joseph, however, demonstrated inadequate knowledge of the curriculum as they could not vary the sources of information for the content and strategies of their lesson and as they often misspelt the success criteria of biotechnology. Some decisions they made in the course of their planning and their initial teaching of biotechnology did not reflect the principles and requirements of the curriculum.

As far as classroom management was concerned, all participant teachers demonstrated some level of knowledge of pedagogy. They could easily notice students who were not paying attention or who were thrown off-track. All teachers also incorporated formative assessment in their lesson, thus demonstrating their knowledge of formative assessment.

James exhibited a unique knowledge of self which the researcher did not observe in the other two participants. He cited his academic qualification as a limitation to content mastery of biotechnology. For this reason, he read widely from different sources and consulted a variety of documents in his preparation and planning to remedy his inferior knowledge. The result of this self-awareness was that, of all the participants, he planned and taught organised and rich lessons, marked by high level content knowledge and good teaching strategies. He developed practical and relevant content representations which enabled him to teach difficult and abstract concepts in ways that were accessible to students. He also varied the teaching strategies very well and displayed knowledge of conceptual, procedural, societal and technical aspects of the subject compared to Joseph and John.

There are other knowledge bases apart from the knowledge bases which this study identified among the teachers participating in this study. A study by Moreland et al. (2006) and Garritz and Velaquez (2009) identified other important knowledge bases teachers need to have to teach biotechnology very well in addition to the ones identified in this study. These included knowledge of history, knowledge of context, knowledge of argumentation, knowledge of ethics, and knowledge of nature of biotechnology and its characteristics. None of these knowledge bases was identified among teachers who participated in this study. There is need for pre-service training to incorporate these knowledge bases in its training schedule so trainee teachers can acquire them and relate them to the teaching of biotechnology.

These knowledge bases have a very big impact on students' understanding of biotechnology. For example, history provides context for current events taking place in biotechnology, while understanding context is essential for accurately interpreting situations, as complex processes occur in biotechnology applications (Amin, Samian, & Haron, 2011). Argumentation skills are crucial because they facilitate critical thinking and effective communication, while ethical considerations inform responsible actions, as there are many applications of biotechnology which are considered to be unethical (O'Mathuna, 2007). Joseph and James demonstrated to have some knowledge of ethics because they were able to provide correct answers to a question related to ethics while John showed lack of this knowledge.

Theoretical findings of the study

On the basis of the findings of this research study, there was no reciprocal relationship among TPKB, TSPCK and classroom knowledge bases as the consensus model shows (see figure 2.12). However, the study established a collaboration between knowledge bases in the TPKB and the components of TSPCK, although it was difficult to determine the level at which one influenced the other. Thus, the lines drawn between the levels only serve to show there is a relationship and collaboration between them without specifically determining the level at which one influences the other. Therefore, in light of this, each knowledge base was analysed independently.

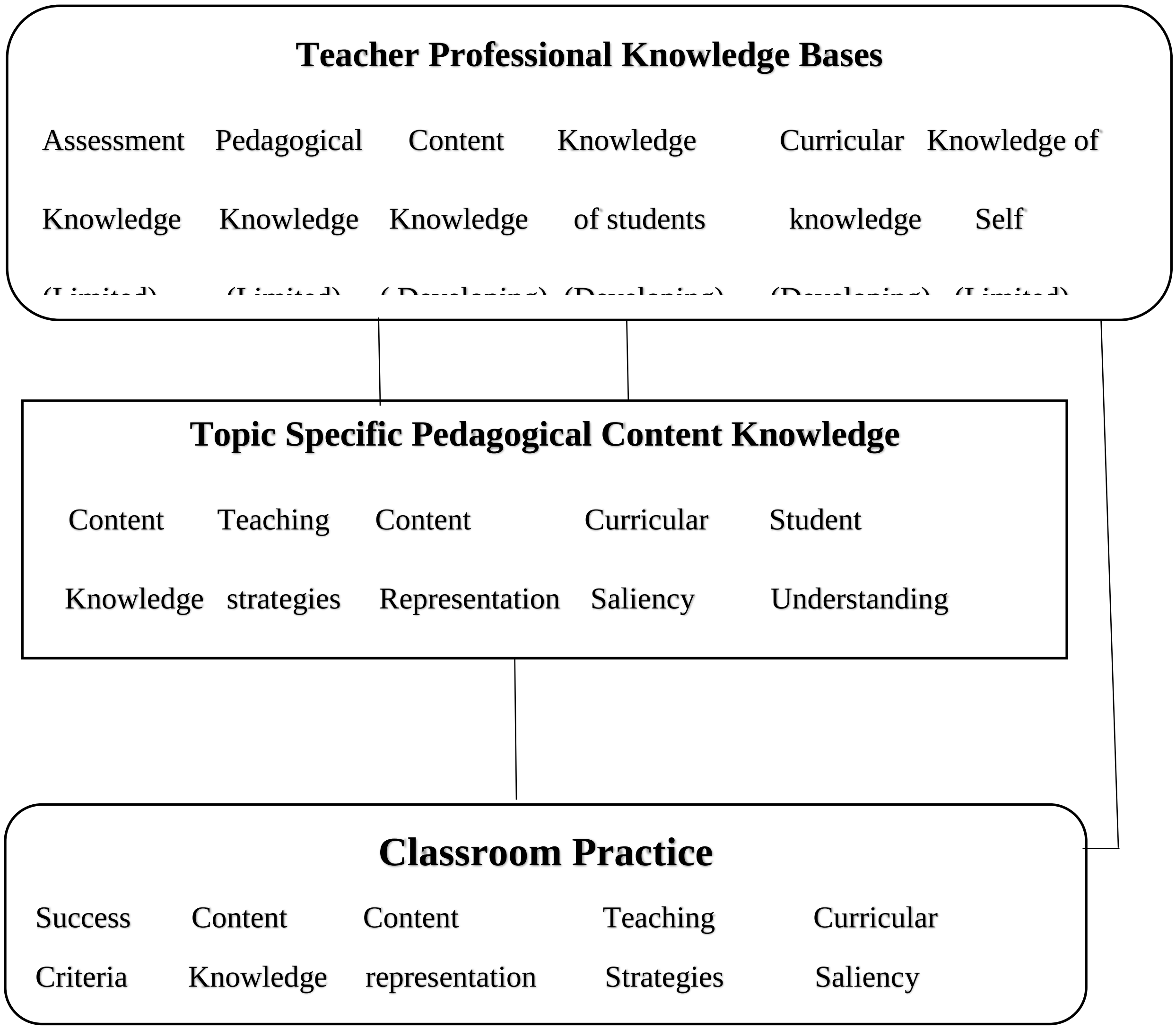


Figure 4.4: Theoretical Framework which includes Findings

Knowledge of self was added to TPKS knowledge as the researcher observed it in James' CoRe. The researcher placed knowledge within TPKS because James indicated that he put more effort into reading widely to make up for his inadequacies in content mastery as a result of his inferior academic qualification. The researcher's assumption was that all the three teachers possessed all the knowledge bases as part of the TPBK as they had all been oriented to the curriculum and as they had all learnt pedagogical knowledge during their teacher training.

The knowledge bases in TPBK were rated using the procedure described in chapter three, adapted from Mavhunga & Rollnick (2011) and Mphathiwa (2019). The components of TSPCK, which included content knowledge, teaching strategies, content representation and curricular saliency, were rated using different instruments described in chapter three. The primary instrument used to rate most of the components of TSPCK was lesson observation. At classroom practice level, the researcher described what he observed in the course of the lesson or what the participants demonstrated in the course of the lesson (figure 4.4). In the classroom, the researcher focused attention on statement of success criteria, manifestation of content knowledge, use of content representations or illustrations, methods of evaluation used, variation of teaching strategies and curricular saliency.

As can be seen from the study, biotechnology is a complex and unique topic of study due to its incorporation of many abstract concepts. This calls for teachers to invest huge amounts of time, effort and innovation in preparing and planning lessons on the topic to teach it effectively. One of the challenges students will face with understanding the processes of biotechnology is that they occur at a microscopic level and so cannot be observed. Therefore, teachers need to be innovative by identifying resources in the local environment to help illustrate the abstract concepts and processes in ways that they will be easily accessible to learners. Also, in addition to innovation, teachers need to familiarise themselves with as many sources and resources on biotechnology as possible to deepen and broaden their content knowledge of biotechnology. By reading widely and frequently on biotechnology, teachers will also stay abreast with emerging issues as well as changing information about biotechnology, thus reducing chances that teachers will communicate mistaken or out-of-date information.

Teachers need also develop capacity for identifying teaching strategies to assist them to teach concepts in biotechnology effectively. But they also need to strive to master the ability to vary teaching strategies during the lessons, with an eye on topic-specific strategies suitable for addressing different success criteria of the topic. Knowledge of self is another vital knowledge base teachers need to strive to possess to assist them in their planning, preparation and implementation of lessons on biotechnology.

Another knowledge base that enables teachers to teach successfully biotechnology is knowledge of curriculum. It is always critical that teachers understand the success criteria, teaching, learning and assessment activities, methods and resources. This is important as it assists teachers to stay on course in their planning, teaching and evaluation of lessons, ensuring that they do not introduce content that is beyond the level of the learners or irrelevant to them. Attending SMASSE In-service trainings will go a long way in acquainting teachers with the curriculum demands and requirements and equip them with the skills they need to plan, teach and evaluate knowledge of biotechnology effectively.

Teachers need to understand the importance of lesson planning and develop lesson plans for their lessons on biotechnology. Lesson plans will not only spell out the content, methods they would use to teach biotechnology, but would also spell out resources that would be used to teach the concepts under different success criteria and highlight the prior knowledge which they would use in their introduction to delve into the new topic as well as to correct misconceptions students nurse about biotechnology. Teachers can also use the lesson plans as bases for reflection and self-evaluation, thus facilitating overall improvement of teaching.

5.10 Chapter summary

This chapter presents the findings of the research study in section 4.1 and discusses these findings in section 4.2. It explores the different knowledge bases of the teachers using their CoRes (Content Representations), observed lessons, interviews, tests, and recommended textbooks. The biotechnology test, observed lessons, CoRes, and interviews revealed that the teachers possessed varying levels of content knowledge.

The study found that the participating biology teachers had different levels of content knowledge. All teachers demonstrated a notable knowledge of curriculum, assessment, pedagogy, and students. These knowledge bases align with the teacher’s professional knowledge bases (TPKB) from the consensus theoretical framework. Additionally, the knowledge of self was found to influence one participant's teaching, fitting within the same TPKB.

However, knowledge of students was categorised within the topic-specific PCK (Pedagogical Content Knowledge) alongside content knowledge, as the study focused on biotechnology, a specific topic where content was transformed into a teachable form. In the topic-specific PCK, teaching strategies were examined. Although two textbooks (Avis et al., 2018 and Njolinjo, 2014) provided some topic-specific strategies, the teachers did not use them. Instead, they adapted them into simple question-and-answer and group work methods to address recall or comprehension questions.

Within the TSPCK (Topic-Specific Pedagogical Content Knowledge), it was discovered that teachers used their biotechnology content knowledge differently and possessed some prior knowledge of students' understanding and teaching difficulties related to the topic. The teachers also demonstrated knowledge of content representation and curricular saliency.

The chapter also investigated the teachers' biotechnology lesson planning and implementation. It was found that two teachers did not write lesson plans, affecting their lesson delivery, unlike one teacher, James, who consistently wrote lesson plans.

The next chapter concludes the study by summarizing the research results according to the five research questions. It discusses the theoretical findings that contribute to new knowledge, revisits the study's methodology, and outlines the implications of the results and recommendations for knowledge bases in teaching biotechnology as a topic.

CHAPTER FIVE

CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS

5.1Chapter overview

This chapter concludes the research study by synthesising discussions from the previous chapters. It presents the summary, conclusions, and implications derived from investigating how secondary school biology teachers utilised their knowledge bases in teaching biotechnology. Introduced into the senior secondary school curriculum in 2013, biotechnology is a relatively new topic, classified under the challenging core element of genetics and evolution for both teachers and students.

The chapter also provides recommendations for individuals and organisations and proposes areas for future research. The study was conducted at three different schools in the Central West Education Division. The respondents were three biology secondary school teachers selected through purposive sampling, targeting those teaching Form Four classes where biotechnology is taught. A qualitative case study method was employed, generating pertinent data through tests, interviews, observed lessons, and CoRes (Content Representations).

5.2 Summary of findings

This section gives a summary of the results of the study based on findings on the research questions. The aim of the study was to investigate the biology teachers' knowledge bases used to teach biotechnology topic. The study was guided by the adapted Consensus Model framework of teacher professional knowledge (2015). The main research question was answered using five specific research questions as follows:

5.2.1 Specific research question one: How much content knowledge of the biotechnology topic do biology teachers have?

The topic is covered by six success criteria as follows: giving examples of plant and animal breeding, describing the applications of biotechnology, describing the process of genetic engineering, explaining how insulin is produced, discussing other applications of genetic engineering, and discussing the ethical implications of biotechnology. All participants demonstrated an understanding of plant and animal breeding and various applications of biotechnology. They were somewhat able to explain genetic engineering, but struggled to clearly articulate the ethical implications of biotechnology. Joseph and John also showed a lack of knowledge about the history of biotechnology. Overall, all the teachers exhibited some problems with the content.

5.2.2 Specific research question two: What topic-specific teaching strategies do biology teachers use in teaching biotechnology concepts?

The findings showed that the teachers mainly used lecture methods, question-and-answer techniques, group work, and presentations. However, despite including strategies like debate and discussion in their CoRes, these were not utilised in the classroom. The recommended textbooks suggested teaching strategies such as field work, debate, group work, and pair work for specific concepts. The teachers did not use these strategies, which could have helped students better understand the concepts, as each strategy followed immediately after a concept in the textbooks. While the teachers tried to engage students in relevant group activities, the outcomes were not used to enhance understanding.

5.2.3 Specific research question three: What knowledge of students' conceptions and learning difficulties do biology teachers have about biotechnology?

The study revealed that each teacher had some awareness of what their students knew and their possible misconceptions. The teachers emphasised the importance of prior knowledge in teaching biotechnology concepts. The findings also indicated that the knowledge of students was a key component of TSPCK (Topic-Specific Pedagogical Content Knowledge), which appeared to be a developing knowledge base among the teachers, as shown in the CoRes. However, in the classroom, the teachers were unable to effectively utilise this knowledge, which would have enhanced their teaching. Each teacher identified different misconceptions their students had that could be corrected. For instance, John knew his students thought that only animals have genes; a misconception originating from the genetics topic, but he was unable to use this knowledge to help students correct this misconception when teaching about animal and plant breeding.

5.2.4 Specific research question four: How do biology teachers assess students' knowledge and understanding of biotechnology concepts?

The study revealed that while teachers were aware of the importance of assessment, their use of it was limited. They understood that formative assessment should be continuously used in classrooms to ensure effective and efficient teaching and learning. The results showed that teachers mainly used oral questions at the beginning, during, and at the end of each lesson. At the beginning, they checked for prior knowledge or misconceptions. During the lesson, they assessed students' understanding of the material being taught, and at the end, they ensured students had grasped the lesson content. Occasionally, teachers used group work to assess students' knowledge before teaching a subtopic. However, none of the teachers utilised written assessments. Only one teacher included some questions in his lesson plans for the introduction and conclusion of lessons, but most of these questions were of low cognitive demand. Additionally, the teachers did not prepare summative assessments during the period the topic was being taught. Nevertheless, it was noted that the teachers were able to use formative assessment in their lessons which was the main area of study as the researcher wanted to find out how the teachers were able to use their knowledge base of assessment in the teaching of biotechnology concepts.

5.2.5 Specific research question five: How do biology teachers use the biotechnology curriculum when planning and implementing the lessons?

The findings showed that teachers varied in their lesson planning and implementation. Joseph used the syllabus to identify subtopics, suggested teaching and learning resources, and possible teaching strategies, but relied on only one recommended textbook for content. During his lessons, he used lesson notes and charts with sketchy illustrations for different concepts. James, on the other hand, utilised the syllabus, schemes of work, lesson plans, four different recommended textbooks, and additional materials from a SMASSE workshop. During his lessons, James brought various textbooks, chart papers with illustrations, and plain chart papers for student group work discussions. John used only a recommended textbook for planning because he did not have a syllabus. For his lessons, he brought only the textbook and chalk to the classroom.

The findings also showed that teachers relied heavily on the recommended textbooks when teaching the topic. Two of the participants used the same single textbook as their sole source of content knowledge for the entire topic.

5.3 Pedagogical Content Knowledge (PCK) as a construct in Biology

This study examined how biology teachers utilised their knowledge bases in teaching the biotechnology topic. The results were discussed within the theoretical framework adapted from the Consensus Model (Gess-Newsome, 2015), detailed in section 2.3 and replicated in Figure 5.1. This model indicates that teachers have professional knowledge bases encompassing content, pedagogy, curriculum, students, and assessment. These knowledge bases both influence and are influenced by topic-specific PCK (Pedagogical Content Knowledge), which includes components such as instructional strategies, students' understanding and teaching difficulties, curricular saliency, and content representations.

The study found that topic-specific PCK is both influenced by and influences classroom practice, which in turn interacts with the teacher's professional knowledge bases. These theoretical relationships were investigated, and the study also aimed to identify additional knowledge bases affecting the teaching of biotechnology beyond those provided in the model. Knowledge of self was identified as a knowledge base and was added to the teacher's professional knowledge bases (TPKB). Classroom practice was included in the model as it is where most knowledge bases, including individual teachers' PCK, are observed.

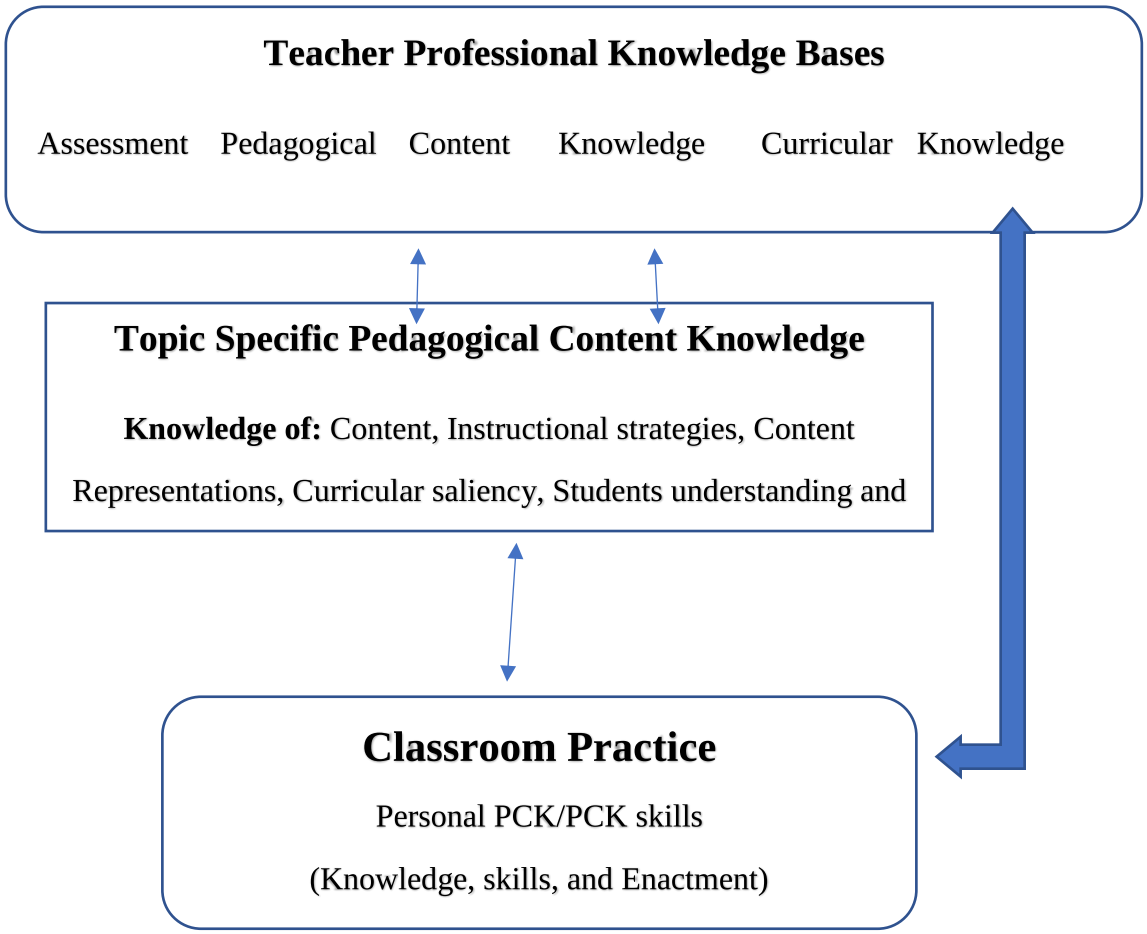


Figure 5.1: An adapted Consensus model of teacher professional knowledge framework (Gess-Newsome, 2015)

To examine these knowledge bases, the success criteria of each lesson were compared with the observed lessons to determine if the content was delivered using appropriate teaching strategies as outlined in the TSPCK framework. The teacher was expected to incorporate components of TPKB (Teacher Professional Knowledge Base) into creating a detailed lesson plan and managing the class effectively. This included understanding the curriculum, planning assessments to evaluate student progress, and being aware of students' prior knowledge. All these elements are interconnected, linking TPKB with TSPCK and its application in the classroom.

5.3.1 Teacher Professional Knowledge Bases (TPKB)

After analysing the CoRes, lessons, and interviews, the findings showed that the teachers had some knowledge of the content they needed to teach under the biotechnology topic. They also had some awareness of their students' existing knowledge and misconceptions about biotechnology concepts. The teachers understood the curriculum requirements, although they often relied heavily on textbooks that did not always align with the lesson outcomes. Without using both the syllabus and the textbooks along with teachers' guides, the teachers sometimes taught content that was either too advanced or too basic for their students.

The results also indicated that the teachers were familiar with appropriate assessment methods. They primarily used formative assessment, which the curriculum emphasises, though they mostly asked recall-type questions. The teachers demonstrated effective class management by ensuring that students were attentive and not disruptive. They also ensured that students completed assigned activities within the allocated time, showcasing their pedagogical knowledge.

These findings suggest that the teachers possessed professional knowledge bases, including knowledge of assessment, pedagogy, curriculum, students, content, and self. According to the adapted model, these six knowledge bases should influence topic-specific pedagogical content knowledge (TSPCK), and TSPCK should, in turn, influence the professional knowledge bases (TPKB), creating a reciprocal relationship. Both TPKB and TSPCK influence classroom practice and vice versa, as indicated by two-way arrows in Figure 5.1.

However, the analysis of this study's findings suggests some deviations from this model, which are discussed in the section that follows.

5.3.2 Topic-specific Pedagogical Content Knowledge about biotechnology

Apart from the knowledge bases described in section 5.3.1, topic-specific pedagogical content knowledge (TSPCK) was also investigated. TSPCK is the foundation through which knowledge of a subject is transformed into teachable content (O'Brien, 2017). It includes various components such as teaching strategies, content representation, curricular saliency, knowledge of students' understanding, and teaching difficulties related to the topic. The findings for each component of TSPCK are detailed in the following sections.

5.3.2.1 Teaching strategies

Mavhunga and Rollnick (2016) define teaching strategies as methods and procedures used to gauge students' understanding or confusion about a concept. In this study, teaching strategies encompassed the methods and approaches teachers employed to ensure that students grasped the material. Avis et al. (2018) and Njolinjo (2014) suggested some topic-specific teaching strategies, such as fieldwork and individual exercises, which the teachers did not implement. The teachers cited time constraints as the reason for not using these strategies.

John and Joseph used Njolinjo (2014) as their primary reference textbook throughout the topic. Instead of the suggested strategies, the teachers modified their approach by substituting simple question-and-answer techniques and group work to assess students' understanding. They replaced individual exercises with oral questions and turned fieldwork into homework assignments. James enhanced the group work strategy by providing students with different textbooks to either answer questions or develop a process for a concept.

Although the syllabus recommended the use of ICT as a resource, the teachers were unable to utilise it due to the lack of ICT facilities in the schools

5.3.2.2 Content representations

Gess-Newsome (2015) describes content representations as various methods used to illustrate a topic, including photographs, diagrams, simulations, tables, and both oral and written presentations. In this study, this component was not fully incorporated to demonstrate the transformation process in their CoRes. Avis et al. (2018) and Njolinjo (2014) provided some representations and activities that could have made the content easier to understand. However, Joseph and John did not utilise these activities and illustrations. James, on the other hand, effectively used a diagram from Avis et al. (2018) showing the process of genetic engineering, transferring it onto a large chart paper for his lessons.

Şen (2014) argues that teachers with strong content knowledge are better equipped to use illustrations and drawings effectively in their teaching. Joseph employed some sketchy illustrations, but John did not use any illustrations or pictures. This suggests that both Joseph and John lacked the knowledge on how to best present the genetic engineering process to their students.

5.3.2.3 Students' prior knowledge

This component focuses on integrating crosscutting concepts into a topic and understanding students' prior knowledge or misconceptions. It is a key element of TSPCK that was well-developed among the three participants, as described in their CoRes. Each teacher had an understanding of their students' existing knowledge and potential misconceptions.

In interviews, the teachers explained that students were expected to have prior knowledge from the genetics topic, including genes, DNA, and chromosomes, as well as an understanding of mitosis and meiosis from their study of reproduction. John added that his students had previously learned about plant and animal breeding in agriculture lessons he taught in the previous year when they were in Form Three. Joseph identified some misconceptions, such as students not recognising the role of yeast in biotechnology and confusing plant and animal breeding with speciation, which was covered just before biotechnology under the core element of Genetics and Evolution.

Despite this awareness, Joseph and John did little to assess students' prior knowledge. It was anticipated that teachers would use the initial lessons to identify gaps, areas of difficulty, or misconceptions and address them in subsequent lessons.

5.3.2.4 What makes the topic difficult to teach

The teachers identified several resource-related challenges in their CoRes, including a lack of teaching and learning materials, reference books, hands-on activities, experiments, and field trips. James, in particular, noted that he struggled with understanding some concepts due to his educational background. During interviews, both Joseph and John acknowledged that students' misconceptions as being difficult to correct easily. What the teachers thought would be straightforward for students often proved to be challenging in the classroom.

5.3.2.5 Curricular saliency

According to Mavhunga and Rollnick (2016), curricular saliency involves determining what is essential for teaching, how to sequence concepts within a topic, what to introduce first, and what to postpone for later. All the teachers were able to align the content with the correct Big Ideas in their CoRes. However, the primary issue they encountered was a lack of rationale for the specific sequence of subtopics they chose. During instruction, the teachers adhered to the sequence of concepts outlined in the syllabus or textbooks. Most textbooks follow the syllabus sequence. However, John missed some crucial information because he relied on a single textbook that did not cover all the required content.

5.3.3 Summary of the findings about TSPCK

The analysis of the components of TSPCK revealed that not all teachers demonstrated all five components effectively. While all teachers recognised and struggled with certain content, particularly terminology such as "recombinant DNA," "plasmid," and "clone," they used some teaching strategies that were not mentioned in interviews, such as the lecture method. All participants employed subject-specific teaching strategies like group work and question-and-answer techniques. James, however, excelled in creating clear representations, illustrations, and diagrams, which helped him explain genetic engineering more effectively. In contrast, Joseph used a sketchy diagram that was not well understood by students, and John, despite knowing about students' understanding and learning difficulties, failed to address them effectively in class. For instance, although John identified a common misconception that “only animals have DNA while plants do not,” he struggled to provide a clear explanation when questioned by a student.

Similarly, Joseph and James were unable to use their knowledge of difficult areas to facilitate better understanding, particularly regarding the process of genetic engineering. The teachers largely adhered to the syllabus and textbooks for guidance on content and sequencing. However, John's reliance on a single textbook led him to overlook important success criteria outlined in the syllabus, thus failing to meet curriculum objectives.

Furthermore, the teachers did not demonstrate several topic-specific pedagogical content knowledge components as described in the literature, such as the history of biotechnology, ethical considerations, and argumentation skills. They missed opportunities to provide historical context for biotechnology, address ethical issues related to its applications, and employ various topic-specific teaching strategies.

5.4 Implications and recommendations

This study aimed to examine how biology teachers utilised their knowledge bases in teaching biotechnology. The findings have important implications for biology teachers, academics, and curriculum developers regarding the knowledge bases employed in teaching this subject.

The results indicated that the biology teachers in the study had inadequate content knowledge and struggled with understanding certain biotechnology concepts and their connections to previously learned topics such as genetics, evolution, and reproduction. The lack of exposure to biotechnology during their pre-service training made it challenging for them to grasp the content. This issue is prevalent among current secondary school teachers, as many did not encounter biotechnology during their teacher training and are now facing it for the first time as a standalone topic. This highlights the need for in-service teacher education to address these gaps and improve biotechnology instruction, as it was found that the teacher who attended the Biotechnology in-service training had better content knowledge compared to those who did not attend the in-service training.

The study also revealed that the teachers lacked knowledge of specific teaching strategies for biotechnology concepts, such as virtual demonstrations that illustrate abstract processes like genetic engineering. Teachers mostly relied on generic subject-specific strategies rather than employing topic-specific methods. Therefore, the curriculum developers should ensure that they provide and suggest topic-specific teaching strategies instead of providing generic strategies, as is the case in the current syllabus for biology. However, there is a need to investigate more about the type of teaching difficulties associated with the topic, possible teaching strategies and to evaluate the available teaching and learning materials.

The study, which involved experienced teachers, demonstrated that experience alone does not always lead to the development of topic-specific pedagogical content knowledge (TSPCK). For instance, James benefited from textbooks and the SMASSE program, which helped him develop content knowledge, understand students' prior knowledge, and refine teaching strategies. However, despite attending SMASSE programs in chemistry and mathematics, Joseph and John did not effectively transfer their general pedagogical content knowledge to biotechnology teaching.

These findings suggest two important implications: First, the SMASSE in-service program needs to be enhanced, as it has shown potential in supporting teachers' development. Collaboration in teacher development should be encouraged. Second, the current SMASSE setup, which focuses on training teachers in only one subject per year, limits the ability to address all subjects. This indicates a need for a more comprehensive approach to teacher development that covers all relevant topics.

The findings also revealed a lack of reflective practice among the teachers. Although SMASSE advocates for the PDSI (Plan, Do, See and Improve), none of the teachers effectively adhered to this philosophy. There is a need for research to explore what prevents biology teachers from reflective practice.

Teachers should be made aware that improving their knowledge of assessment enhances their understanding of students' needs. Biology teachers need to adapt the curriculum based on these needs, which will also deepen their understanding of the curriculum. This, in turn, will enable them to employ more effective, topic-specific instructional strategies, including tailored activities and representations for specific concepts. Continuous professional development programs should include training on various types of assessment, as the study found that the teachers' knowledge of assessment was lacking. Enhanced assessment knowledge will positively impact teachers' pedagogical content knowledge (PCK) and improve classroom teaching and learning.

Additionally, the study found that teachers primarily relied on textbooks for content knowledge. However, some recommended textbooks lacked illustrations and activities that could stimulate students' critical thinking. The study recommends that curriculum developers ensure publishers provide textbooks with clear illustrations and engaging activities that align with the syllabus to facilitate student understanding. Teachers' guides should be developed to assist teachers in coping with the topic of biotechnology.

5.5 Areas for further research

There is a great need for further research on the result that the underqualified teacher demonstrated good content knowledge. Why should someone deemed to be underqualified display good content mastery? Does it mean one's initial qualification does not matter?

This study concentrated specifically on the knowledge bases for teaching biotechnology. Future research should explore how teachers' beliefs affect the teaching of biotechnology, which was not covered in this study. Exploring these elements will help determine how they impact the knowledge bases and affect teaching practices for various topics within the Malawian context.

Additionally, while this research addressed the teaching of biotechnology as a whole, future studies could benefit from focusing on specific concepts within biotechnology, such as genetic engineering. This targeted approach could provide more detailed insights into the teaching of individual topics.

5.6 Summary of the study

This chapter summarises the study by outlining the results presented in Chapter 4 and discussing them within the same chapter. The conclusion highlights the findings related to the main research question, addressed through five specific research questions.

The study revealed that the teachers possessed various knowledge bases, including content knowledge of biotechnology, knowledge of students, pedagogical knowledge, assessment knowledge, and curriculum knowledge. However, many of these knowledge bases were still in development. These insights were gathered through interviews, lesson observations, and content representations (CoRes). Despite this, the findings also indicated that the participating biology teachers lacked several important topic-specific knowledge bases necessary for teaching biotechnology effectively, as identified in the literature. These gaps included knowledge of ethics, teaching strategies, content representation, certain content concepts, argumentation, and the history of biotechnology.

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The chapter includes implications for curriculum developers and pre-service training institutions based on the identified gaps in teaching biotechnology. Recommendations are made for enhancing teachers' knowledge bases to improve teaching effectiveness. It is suggested that curriculum developers integrate innovative teaching strategies into the curriculum and ensure that textbooks provide detailed illustrations and representations to aid student comprehension. Textbooks should also serve as a valuable resource for pedagogical content knowledge (PCK) for teachers.

Future research should explore the result that the underqualified teacher demonstrated good content knowledge, that is, whether one’s initial qualification does matter or not.

There is a need to explore the effect of teachers' beliefs on the teaching of biotechnology which were not covered in this study. Additionally, focusing on specific concepts within biotechnology, rather than the entire topic, could provide more detailed insights.

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Appendix A: First interview with the biology teacher questions

1. What is the class size?
2. What is the catchment area of the school?
3. How many schools have you taught before joining this school? List them
4. What kind of support do you receive from the administration as you teach biology?
5. What kind of relationship do you have with other members of staff in your department?
6. Briefly describe how will you plan your lessons for this biotechnology topic?
7. What are your sources of references?
8. Do you know any specific teaching strategies that are particularly useful in teaching biology in general and biotechnology concepts in particular?
9. What factors did/ do you take into consideration in the decision-making process?
10. Are biotechnology concepts more difficult to teach compared with other topics?
11. What may be the difficulties/ obstacles, if any, that you would foresee/ you have experienced in teaching the new Biotechnology in your school?
12. How do you overcome these problems?
13. Overall, do you feel confident teaching this new Biotechnology? Why?

Appendix B: Pre-lesson interview guide

A. **Knowledge of subject matter**

1. What is (are) the key concept (s) in the lesson that you are about to teach?
2. What specifically do you want your students to learn about in today's lesson? Why do you think they are important?

B. **Knowledge of learners**

3. What is the aim of the lesson?
4. What do you think students have already known about this lesson? Where do you think they may have learnt that? If from the curriculum, which part of the curriculum?
5. What concepts may be difficult for your students to grasp in this lesson? Why do you think so?

C. **Knowledge of teaching strategies**

6. Which teaching strategy will be employed to ensure successful delivery of the lesson?
7. Describe what would happen during the beginning, middle and end of the lesson.
   a. What will you do? b. What will the students do?
8. Why did you plan to carry out your lesson in this way?

D. **Knowledge of curriculum**

9. What is the main teaching resource that you base your lesson on? What modifications have you done?

E. **Knowledge of assessment**

10. Have you prepared an assessment instrument to evaluate whether the aim of the lesson is achieved?

Appendix C: Post – Lesson interview guide

1. How did the lesson go?
2. Did any unplanned incidents/unanticipated moments (e.g. students' questions, deliberate change/modifications in lesson plan) happen in the lesson(s)? If so, why?
3. Did the modifications on the materials work well as expected? Why?
4. You didn't modify any of the textbook content. Is it because you think the flow of the textbook material works well or you didn't have any time to modify the materials?
5. Do you think your students learnt well in the lesson? How do you know that?
6. Did you observe any difficulties in students' learning in this topic in the lesson?
7. Could you identify any misconceptions/ errors of the students in this topic in the lesson?
8. Will you do any follow-up assessment task on the content of this lesson? In what ways?

   What do you want to assess in this assessment task?
9. You used (an animation, picture, analogy) to help students learn…. Why? Are there any particular reasons for the use of this (strategy) for teaching?

   Adapted from Chung & Yung (2018)

Appendix D: Final interview questions for the teacher

1. Overall, do you think that your lesson(s) on biotechnology were successful, why? Are there any successful sections or lessons that you can still remember?
2. What area(s) do you want to improve? Why?
3. What are the difficulties you encountered in your first round of teaching the topic biotechnology?
4. Can this year's teaching experience of the topic biotechnology help you teach this topic again? If so, how?
5. If you were the curriculum planner, would you still retain the topic of biotechnology in this curriculum after teaching this topic? If so, what is the purpose of including this topic? If not, why not?

Adapted from Chun & Yung (2018)

Appendix E: Lesson observation checklist

Date: ____

Name of the Teacher: ______________________________

Name of the School: _______________________________

Class: ____

Topic: ____

Number of present students: ______________ Male: ___________Female: ________________

Rate each of a number of key indicators in different categories, from 1 (not at all) to 5 (to a great extent). It is important to support your rating with evidence.

Components of PCK (Knowledge of ……….)	**Observation facts**	**1**	**2**	**3**	**4**	**5**	**Evidence of the rate and Comments**
Students	Science being interesting for all students						
Science	Studying a few fundamentals concepts						
Science	Content that is meaningful to the student's experience and interest						
Science content	Demonstrate mastery of content in terms of accuracy, correctness and appropriateness						
Teaching	Lesson development used various teaching methods						

Teaching	Providing opportunities for scientific discussion among students						
Teaching	Guiding students in active and extended students inquiry						
Students	Groups working cooperatively to investigate problems or issues						
Resources	Learning science actively by seeking understanding from multiple sources of information including books, internet, media reports, discussion and hands on investigations						
Goals	Learning broader concepts that can be applied in new situations						
Assessment	Assessing understanding and its application to new						

	situations, and skills of investigation, data analysis and communication						
Assessment	Ongoing assessment of work and the provision of feedback that assists learning						
Assessment	Selects, constructs, and uses assessment strategies appropriate to the learning outcomes.						
Assessment	Assesses student learning progress and adjusts instruction during the lesson.						

Adapted from Mim, Rahman and Jahahara (2017)

Appendix F: Consent form for teachers' participation

Title of research project: Investigating biology teachers' knowledge bases for the teaching of biotechnology in Malawi Secondary School Science classrooms

I, ______________________________________, give my consent for the researcher, Mr. George Vakusi, a PhD student of the University of Malawi, Chancellor College, Department of Curriculum and Teaching Studies (CATS) to audiotape the interviews conducted with me or video record my lessons in biotechnology for his research on Investigating biology teachers' knowledge bases in the teaching of biotechnology.

- I realize that there are no risks attached to my involvement in this study and that the study is being conducted for educational purposes only.
- I understand that I participate voluntarily in the study.
- I consent that the audio/video recording will be done by the researcher.
- I understand that the contents of the audio or video tapes will be used only for the purposes of this research and only by the researcher and kept strictly confidential.
- I understand that only the researcher will have access to the audio or video recordings.
- I understand that only the interviews will be recorded in about 30 minutes.
- I understand that the audio or video recordings of the interviews and lessons will be destroyed once the study is complete.

Name: ____

Signature: ____

Date: ____

Appendix G: The test for teachers

BIOTECHNOLOGY TEST

Instructions: This test is **NOT** for evaluation but for research purposes **ONLY.**

Answer all the questions in the spaces provided.

1. Hybrid maize is produced by artificial cross pollination.

   a. State **three** advantages of hybrid maize. (3 marks)

   b. Describe how artificial cross pollination is done. (6 marks)

2. a. Name three different kinds of microorganisms used in the manufacturing of industrial products. (3 marks)

   b.Name **three** products produced through fermentation by yeast. (3 marks)

3. a. Define genetic engineering. (2 marks)

   b.What is the difference between a clone and a transgenic organism? (2 marks)

   c. What do you mean by the term recombinant DNA? (2 marks)

4. a. Where are plasmids found? (1 mark)

   b. Why are restriction enzymes called “molecular scissors”? (2 marks)

   c. Name the enzyme which joins DNA fragments. (1 mark)

5. Name any **two** proteins and **two** enzymes obtained by recombinant DNA technology.

(4 marks)

6. Explain how recombinant DNA technology is useful for pharmaceutical companies.

(3 marks)

7. Name any **two** diseases for which bioengineered vaccines have already been developed. (2 marks)

8. a. Describe **three** usefulness of transgenic organisms. (6 marks)

b. Mention **two** methods used in the production of transgenic organisms. (2 marks)

c. Describe any **one** method mentioned in (**b**). (10 marks)

9. Describe any three ethical implications of biotechnology on the society. (6 marks)

End of the question paper

Appendix H : Letter of Introduction from University of Malawi

Chancellor College

SCHOOL OF EDUCATION

DEPARTMENT OF CURRICULUM AND TEACHING STUDIES

To: Whom it may concern

From: PG office, Curriculum and Teaching Studies department

Date: 6th January, 2021

LETTER OF INTRODUCTION FOR GEORGE MACDONALD VAKUSI

The bearer of this letter, **GEORGE MACDONALD VAKUSI** (PHD-ED-SCE-MAT-04-19), is a postgraduate student in the School of Education at the University of Malawi, Chancellor College. He is pursuing doctor of philosophy in science education in Curriculum and Teaching Studies department.

George McDonald Vakusi is currently conducting his fieldwork, collecting data for his study. Any assistance rendered to him will be greatly appreciated.

Should you require additional information concerning this letter, please feel free to contact the undersigned.

Yours sincerely,

Bob Maseko, PhD
PG COORDINATOR
CURRICULUM AND TEACHING STUDIES DEPARTMENT

Email: bmaseko@cc.ac.mw

UNIVERSITY OF MALAWI
CHANCELLOR COLLEGE
6 JAN 2021
CATS DEPARTMENT
P.O. BOX 280, ZOMBA

Appendix I : Letter of Authorisation to conduct research in CWED

REF. NO. CWED. ADMIN 2/1

FROM: THE EDUCATION DIVISION MANAGER (CWED),
P.O. 98, LILONGWE

TO : VAKUSI MACDONALD GEORGE

CC : TO WHOM IT MAY CONCERN

RE : REQUEST TO CONDUCT ACADEMIC RESEARCH IN CWED SECONDARY SCHOOLS

I write to advise that VAKUSI MACDONALD GEORGE has been granted permission to conduct an academic research to collect data for his Doctor of Philosophy in Science dissertation in your schools. The target area for the research is on Curriculum and Teaching

However, the researcher will have to seek individual consent from the participants and that normal classes shall not be disrupted.

You are therefore requested to render to the researcher assistance required.

DIVISION MANAGER
CENTRAL WEST
EDUCATION DIVISION
AUG
DOSS
LILONGWE

PP

J.J. Nkhata
EDUCATION DIVISION MANAGER(CWED)

Appendix J: Initial Content Representations for Joseph

Content representation for teaching Biotechnology

	Big Science Ideas/Concepts				
	A Historical outlook of biotechnology	B Plant and animal breeding	C Genetic engineering (from DNA to recombinant proteins)	D Biotechnological applications towards drugs and food production	E
What you intend the students to learn about this idea	Ordinary application of biotechnology such as local breedings, seed selection, Process of bees production	Different plant and animal breeding is attached with a purpose.	Process of genetic engineering and how it is used in production of human insulin, milk production	Biotechnology is applied in different areas such as i Agriculture ii, Medicine iii, Industries	

Why is it important for students to know this?	Increased understanding lead to increase in appreciation of biotechnology	Because plant and animal breeding is always applied in our communities	Plant and animal breeding on its own is not enough as such to fully understand GMO; genetic engineering help to bridge the gap.	Biote applie differe It is import know of bio in lin real l eg. Hor - fro dru - Pro bee
What else you know about this idea (that you do not intend students to know yet)?	Biblical understanding of the wine that was produced is as a result of biotechnology	Cross breeds of local chickens with Mikolongwe		Produc Vaccine

Difficulties/limitations connected with teaching this idea	Selective breeding in our Communities might not be appreciated by Students as a part of biotechnology		Models and drawings are idealized representations. Limitations of actual observations in real life act as a barrier.	The idea [illegible] production [illegible] hormones c[illegible] difficult to students to appreciate because of [illegible] Concept of endocrine sy[illegible]
Knowledge about students' thinking which influences your teaching of this idea	Students do not often see that the use of yeast is part of biotechnology	Ideas of plant and animal breeding is more likely to be connected with speciation not biotechnology	Production of organisms can be done by manipulating genes not only cross breeding	Students may o[illegible] be aware o[illegible] blood donatio[illegible] Plant and an[illegible] breeding

Other factors that influence your teaching of this idea	Students enjoy learning		The sequence of the curriculum influences how students make links to other topics	Availabil of Hyelin Mikolongw White legh different of maize
Teaching procedures (and particular reasons for using these to engage with this idea)	Question Building: Discussion Students explain to each other in pairs what each one knows about biotechnology	Ask questions why are plants and animals breed	Demonstration: Students develop a detailed steps/ procedure involved in genetic engineering using the chart drawings.	Brainstor list of biotechn applicat towards and foo producti

Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses)	From their discussions, the teacher attempts to listen to students descriptions of different aspects of terms related to biotechnology	When students are answering questions, the teacher listens carefully for their ability to apply to what they know.	Listening for steps that students have able to come up with. This would serve as a bridge to real practical aspect.	Recogni[illegible] of the applicat[illegible] biotech[illegible] and re[illegible] it to modern[illegible]

Appendix K: Initial Content Representation for John

Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses)	From their discussions, the teacher attempts to listen to students descriptions of different aspects of terms related to biotechnology	When students are answering questions, the teacher listens carefully for their ability to apply to what they know.	Listening for steps that students have able to come up with. This would serve as a bridge to real practical aspect.	Recognisin of the applicatio biotechn and rela it to t modern

Why is it important for students to know this?	For easy understanding of the topic.	To know how hybrids are formed	For students to know and apply in real life situation.	To improve health of living organisms.
What else you know about this idea (that you do not intend students to know yet)?	DNA code like: Adenine, Guanine, Uracil, Thymine, cytosine	Exotic breeds can be crossed, Indigenous breeds can also be crossed, depending on desired characteristics	~~The gen~~ Making connection of genetics of mice and human beings. The polymerase chain	Can be applied in agriculture

Difficulties/limitations connected with teaching this idea	It cannot give valid information as biotechnology started very long time ago.	. ~~Easy~~ to transfer disease . Gene pool	. Can transfer gene that can cause a certain effect than preventing	. Causing diseases like B.C health effe
Knowledge about students' thinking which influences your teaching of this idea	. Learning process can be faster as well as teaching process because they already have knowledge from Agriculture	Some students think that DNA is found in animals only and not in plants. need for emphasis.	Some students thinks that DNA is found in animals only and not in plants. need for emphasis.	they thin that food made fr biotechno ie. food products can eat cause disea

Other factors that influence your teaching of this idea My prior knowledge of other subjects and the subject.	It's easy to teach as I also teach cross breeding in Agriculture. Also, the knowledge of selecting seeds for planting from ancestors	It's easy to teach as I also teach cross breeding in Agriculture. Also the knowledge of selecting seeds for planting from ancestors	Knowledge gained from College.	Knowledge in food production such as in agriculture
Teaching procedures (and particular reasons for using these to engage with this idea)	· Inform students when biotechnology started. · Knowledge of ancestors · recent knowledge	· Have local and exotic plants and cross them. · Have local and exotic animals and cross them	· Isolate the gene · Insert in a host · Produce as many copies of the host as possible	· Have fr[illegible] sample · Have plan[illegible] to take genes

Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses)	· Formulating questions or making a survey.	Students discuss and the teacher listens attentively	Doing experiments	Doing experiments · Food technology

Appendix L: Initial Content Representation for James

CURRENT REPRESENTATION FOR TEACHING BIOTECHNOLOG

IMPORTANT OR BIG SCIENCE IDEAS / CONCEPTS				
A	**A. Teaching learners Biotechnology is of a great value because it will assist them to understand the meaning of biotechnology and give examples of areas in which this is being used in our country**	**B application of biotechnology in different discipline with the purpose improving human life.**	**C. To prepare students to be citizens with basic knowledge about genetic engineering (i.e. tools and the process of genetic engineering)**	**D. Cherish some of th discoveries (applicati done through Biotechnology i.e. production of Insulin**
What you intend students to learn about this idea?	**Biotechnology** is the utilization of organisms, part of the organisms and the biological processes for the benefit of mankind. In Malawi the knowledge of biotechnology is being applied in agricultural sector e.g., • Production of hybrid seeds (e.g. Bt cotton by LUANER, DK 9089 by Monsanto and ZM 309 (Msinga banja) by Chitedze research station. • Production of verities of poultry (e.g. breeding of varieties of poultry done at Mikolongwe) • Production of daily cattle (e.g. artificial breeding of daily cattle done at	How biotechnology is being applied in different disciplines e.g. • In medicine: use in development of vaccine and antibiotics e.g. Penicillium notatum is used to make Penicillin used to treate fever • In agriculture: plant and animal breeding using artificial selection where organisms with desired traits are crossed to come up with organisms with desired traits. • Cleaning up and managing the environment by using the bacteria or fungi and enzymes used to	Learners to describe the process of genetic engineering • Genetic engineering (recombinant DNA) as technology which involves altering the genes in a living organism to produce Genetically Modified Organism (GMO). This is done by taking a section of a DNA and putting it into another organism so that it produces useful things. • The basic process of genetic engineering includes i. Remove bacterial DNA (**Plasmid**) ii. Cut the Bacterial DNA with "**restriction enzyme**" iii. Cut the DNA from another organism containing the required	a) Production of insuli • First, insulin produc cell is taken from h pancreas. • The genes are then inserted into plasm of a bacterium call **Escherichia coli**. • The bacterium witl new insulin DNA is cultured and allow multiply in a mediu Nutrient Agar. • The insulin gene in human DNA insert bacteria instructs synthesize human insulin. • The hormone is separated from th bacteria and purif • The Artificial insul sold commercially

	Mbawa Agriculture research Station in Embangweni)	breakdown toxic substances. • In industries: production of food products for human consumption e.g. yoghurt, beer, beer.	trait with the same "restriction enzyme" iv. Insert the cut piece of DNA into the bacteria using the ligase (enzyme glue) v. Reinsert the cut plasmid into the bacteria. When the bacteria are cultured they produces millions of a replica of the foreign DNA. This is called **gene cloning**	control blood sugar i human beings. b) Other applications o biotechnology **i. In Agriculture** Production of genetically modifie crops by adding ger from other plants w the aim of • improving nutrient content and taste e Golden rice • producing high yiel unit area • more shelf life • GMOs use less wat hence resource ser • Resist attack by wo e.g. cotton • Improve milk production **ii. In medicine** • Production of vacc e.g. Hepatitis B vac antibiotics, In manufacturing Ind • production of enzy from cloned genes used in manufactu of products e.g. Amylases used in manufacturing of b and bread

Why is it important for students to know this?	Knowledge of biotechnology will help learners to solve most problems they face today such as low food production, low meet , milk and egg production, diseases and treat waste among others	Learners will be able to understand the importance of studying biotechnology after looking at the impact that biotechnology brings in different discipline in their country, society, homes and later alone in their everyday lives.	This will assist learners to develop scientific attitude like curiosity and creativity this will help them to apply scientific, technological, indigenous and non-indigenous knowledge to help them come up with appropriate solutions to their problems.	This will help learne cherish and underst how biotechnology being applied in dif disciplines for the b of mankind this will them to apply the s principles learnt in daily lives after scho
What else you know about this idea (that you do not intend students to know)?	• The history of Biotechnology begins on the Neolithic Revolution. Throughout the history of agriculture, farmers had unknowingly altered the genetics of their crops through introducing them to new environments and breeding them with other plants. The use of microorganisms in the food processing like; Bread, cheese, wine and beer were reached long ago by various processes of fermentation. • The last revolution in biotechnology began in the late 1970s with the discovery and application of genetic technology and recombinant DNA	Details on how Biotechnology is used in various disciplines	Other examples of genetic engineering and how they are done	•

Difficulties / limitations connected with teaching this idea	• Reference books for additional science are not available. • Lack of teaching aids • Lack of expertise to handle experiments related to biotechnology • Even though biotechnology is covered in the syllabus, its actual application in classes is generally restricted, which causes the students difficulty in understanding and appreciating biotechnology. • Experiments and discussions on genetic engineering and tissue culture processes are difficult	• Lack of teaching aids • Arranging field trips to visit such areas where more knowledge on biotechnology could be obtained may be costly.	• Lack of more hands-on activities and experiments • Lack of teaching aids • Lack of reference books on biotechnology	• Lack of teaching • Lack of referenc on biotechnolog • Lack of enough in teaching this
Knowledge about students' thinking which influences your teaching of this idea.	Learners think that Biotechnology is a new concept. Which cannot be applied at a house hold level, though they are aware of the local processes of beer brewing and bread making but they don't realize that this is part of biotechnology.	• Learners may not be aware that biotechnology is having a greater application in different areas e.g. food production i.e. soya pieces, in forensic sciences where DNA finger printing which is used to identify criminals.	Learners are not much aware of the tools and processes of genetic engineering, hence a need to equip them with the knowledge on the materials and processes involved.	• Not all learne conversant w application of biotechnolog need for ther this concept they develop attitude scier knowledge o biotechnolog

Other factors that influence your teaching of this idea		• Because of the growing impacts of biotechnology in our society, this concept will give them a good platform in making rightful decisions regarding biotechnology.	Knowledge in genetic engineering will give learners a starter pack on how genetic engineering is carried out to come up with use products for human benefit.	Learners to cherish t importance of biotechnology i.e. in production which he save lives of people v sugar disease.
Teaching procedures (and particular reasons for using these to engage with this idea)	**Think pair and share:** in which learners will think on their own i.e. the meaning of biotechnology thereafter sharing their responses with their friends **Discussions**: where students discuss the meaning and how biotechnology is being applied in agricultural sector in Malawi.	**Discussions**: learners being involved in discussions on application of biotechnology in different disciplines there after presenting their findings in plenary. **Field visit:** arranging a field visit to one of the sites where application of biotechnology is being used e.g. Chitedze Research Station to cherish on how production of new varieties of maize is being done or a vist to a local beer brewer to see how biotechnology is applied **Use of a resource person**: who is knowledgeable on issues biotechnology carried out in his area of specialization	**Discussions**: learners discussing the materials required for genetic engineering. **Explanation**: learners / teacher explaining the process of genetic engineering **Questions and answers**: where learners will be involved to give responses posed to them by the teacher or fellow learners.	**Discussions**: where learners will be askec brain storm producti insulin **Brainstorm:** learners be asked to brainstor other applications of biotechnology

Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).	Students giving a) the meaning of biotechnology b) c) Examples of: • new poultry breeds (black australope) • hybrid seeds available in Malawi, e.g. Kanyani, Nsunga banja and DK9089 among others, • cross breeding Malawi Zebu with exotic breeds to come up with breeds which can give more milk and meet.	• Students providing application of biotechnology in different disciplines e.g. In medicine: use in development of vaccine and antibiotics e.g. Penicillium notatum is used to make Penicillin used to treate fever • In agriculture: plant and animal breeding using artificial selection where organisms with desired traits are crossed to come up with organisms with desired traits. • Cleaning up and managing the environment by using the bacteria or fungi and enzymes used to breakdown toxic substances. In industries: production of food products for human consumption e.g.	Students coming up with a) Tools to be used in the process of genetic engineering i.e.; • Cell culture (containing the required gene or DNA sequence) • Restriction endonuclease enzyme (molecular scissors) • Plasmids (obtained from the bacteria having same gene sequence matching those from a required gene) • DNA ligase (molecular glue) • Host bacteria whose plasmid is used to carry the foreign DNA. b) Process • Select a specific endonuclease • Cutting a section of the DNA containing the required genes from the cell culture using the specific endonuclease (molecular scissors) • Using the same restriction enzyme cut a matching DNA from the plasmid • Using ligase join the DNA containing the required genes into the space vacated by the cut DNA of the plasmid.	c) Production of insulin • First, insulin producin cell is taken from hur pancreas. • The genes are then inserted into plasmid of a bacterium called **Escherichia coli**. • The bacterium with t new insulin DNA is cultured and allowed multiply in a medium Nutrient Agar. • The insulin gene in th human DNA inserted bacteria instructs it to synthesize human insulin. • The hormone is separated from the bacteria and purified • The Artificial insulin is sold commercially to control blood sugar in human beings. • However, learners mi think that insulin whi is made available in hospitals comes from plant products. Henc this will clear that misconception d) Other applications of biotechnology **i. In Agriculture** Production of genetically modified

			• Insert the recombinant plasmid (**clonal vector**) back into the Bacteria • The bacteria is allowed to multiply where the foreign DNA is then obtained and preserved or purified to be used for the intended purpose.	crops by adding ger from other plants w the aim of • improving nutrient content and taste e Golden rice • producing high yiel unit area • more shelf life • GMOs use less wat hence resource ser • Resist attack by wo e.g. cotton • Improve milk production **ii. In medicine** • Production of vacc e.g. Hepatitis B va antibiotics, **iii. In manufacturing Industry** • production of enzymes from cl genes to be used manufacturing o products e.g. Amylases which used in manufac of beer and brea

Appendix M: Content Representation (CoRe) for Joseph for teaching Biotechnology topic

	Big Science Ideas/Concepts			
	A. Historical outlook of biotechnology	B. Plant and animal breeding	C. Genetic engineering (from DNA to recombinant proteins)	D. Biote applicati drugs an producti
What you intend the students to learn about this idea	Ordinary applications of biotechnology such as local breeding, seed selection, the process of beer production	Different plant and animal breeding is attached with a purpose	Process of genetic engineering and how it is used in the production of insulin and milk production.	Biotechn applied i areas suc - A - N - I
Why is it important for students to know this?	Increased understanding leads to an increase in appreciation of biotechnology	Because plant and animal breeding is always applied in our communities	Plant and animal breeding is not enough as such to fully understand GMOs; genetic engineering help to bridge the gap	Biotechn applied i disciplin therefor to know biotechn line with situation Hormon producti producti producti yogurt

What else do you know about this idea (that you do not intend students to know yet)?	A biblical understanding of the wine that was produced is a result of biotechnology	Cross breeds of local chickens with Mikolongwe		Producti vaccines
Difficulties/limitations connected with teaching this idea	Selective breeding in our communities might not be appreciated by students as a part of biotechnology		Models and drawings are idealized representations. Limitations of actual observation in real life act as a barrier	The idea producti hormone difficult students apprecia of the co endocrin
Knowledge about students' thinking which influences your teaching of this idea	Students do not often see that the use of yeast is part of biotechnology	Ideas of plant and animal breeding are more likely to be connected with speciation not biotechnology	Production of organisms can be done by manipulating genes not only cross breeding	Students be aware donation and anin
Other factors that influence your teaching of this idea	Students enjoy learning		The sequence of the curriculum influences how students make links with other topics	Availabi Hyelins, Mikolon Leghorn varieties seeds

Teaching procedures (and particular reasons for using these to engage with this idea)	Question building: Discussion. Students explain to each other in pairs what each one knows about biotechnology	Ask questions why are plants and animals breed	Demonstration: Students develop a detailed steps/procedure involved in genetic engineering using the chart drawings	Brainsto biotechn applicati drugs an producti
Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses)	From their discussions, the teacher attempts to listen to students' descriptions of different aspects of terms related to biotechnology	When students are answering questions, the teacher listens carefully for their ability to apply what they know	Listening for steps that students are able to come up with. This would serve as a bridge to real practical aspects	Recogni the local applicati biotechn relating modern

Appendix N: Content Representation (CoRe) for James for teaching Biotechnology topic

	Big Science Ideas/Concepts			
	A. Historical outlook of biotechnology	B. Plant and animal breeding	C. Genetic engineering – from DNA to recombinant proteins	D. Biote applicati drugs an producti
What you intend the students to learn about this idea	Biotechnology is the utilisation of organisms and the biological processes for the benefit of mankind.	• In Malawi, the knowledge of biotechnology is being applied in agricultural sector such as production of hybrid seeds (DK 9089 by Mosanto and ZM 309 (Msunga banja) by Chitedze research station. Production of varieties of poultry (e.g. breeding of varieties of poultry done at Mikolongwe). Production of daily cattle (e.g. artificial breeding of daily cattle done at Mbawa Agriculture research station in Embangweni)	Learners to describe the process of genetic engineering. • Genetic engineering (recombinant DNA technology) involves altering the genes in a living organism to produce Genetically Modified Organism (GMO). This is done by taking a section of a DNA and putting it into another organism so that it produces useful things. • The basic process of genetic engineering includes i. Removing bacterial DNA (plasmid)	How bio is being different For exar • In Me Used produ vaccin antibi horm insuli • In agr plant breed • Clean mana enviro using or fur enzym break substa

			ii. Cut the Bacterial DNA with "restriction enzyme" iii. Cut the DNA from another organism containing the required trait with the same "restriction enzyme" iv. Insert the cut piece of DNA into the bacteria using the ligase (enzyme glue) v. Reinsert the cut plasmid into the bacteria. When the bacteria are cultured, they produce millions of a replica DNA. This is called gene cloning.	• In ind produ food p huma consu as yog beer. • The p produ insuli discus detail
Why is it important for	Knowledge of biotechnology will			

students to know this?	help learners to solve most problems they face today such as low food production, low meet, milk and egg production, diseases and treat waste among others			
What else do you know about this idea (that you do not intend students to know yet)?	The history of biotechnology begins on the Neolithic Revolution. Throughout the history of agriculture, farmers had unknowingly altered the genetics of their crops through introducing them to new environments and breeding them with other plants. The use of microorganisms in the food processing like bread, cheese, wine and beer were reached long time	Details on how biotechnology is used in various disciplines	Other examples of genetic engineering and how they are done	

	ago by various processes of fermentation. The last revolution in biotechnology began in the late 1970s with the discovery and application of genetic technology and recombinant DNA			
Difficulties/limitations connected with teaching this idea	• Reference books for additional science are not available. • Lack of teaching aids • Lack of expertise to handle experiments related to biotechnology.	• Lack of teaching aids. • Arranging field trips to visit such areas where more knowledge on biotechnology could be obtained may be costly.	• Lack of more hands-on activities and experiments. • Lack of teaching aids • Lack of reference books • Experiments and discussions on genetic engineering and tissue culture processes are difficult.	• Lack o aids • Lack o books biotecl • Lack o experti teachir • Even t biotecl covere syllabu applica classes restric causes difficu unders

				apprec biotec
Knowledge about students' thinking which influences your teaching of this idea	Learners think that biotechnology is a new concept which can not be applied at a house hold level, though they are aware of the local processes of beer brewing and bread making but they don't realize that this is part of biotechnology.	Learners may not be aware that biotechnology is having a greater application in different areas. E.g. food production such as soya pieces, in forensic sciences where DNA finger printing which is used to identify criminals	Learners are not much aware of the tools and processes of genetic engineering, hence a need to equip them with the knowledge on the materials and processes involved.	Not all t are conv the appli biotechn hence a them to concept develop attitude biotechn
Other factors that influence your teaching of this idea		Because of the growing impacts of biotechnology in our society, this concept will give them a good platform in making rightful decisions regarding biotechnology	Knowledge in genetic engineering will give learners a starter pack on how genetic engineering is carried out to come up with use of products for human benefit.	Learners the impo biotechn is, insuli which ho lives of sugar dis

Teaching procedures (and particular reasons for using these to engage with this idea)	Think pair and share: in which learners will think on their own, that si, the meaning of biotechnology thereafter sharing their responses with their friends. Discussions: where students discuss the meaning and how biotechnology is being applied in agricultural sector in Malawi.	Discussions: learners being involved in discussions on application of biotechnology in different disciplines there after presenting their findings in a plenary. Field visit: arranging a field visit to one of the sites where application of biotechnology is being used like chitedze research station to cherish on how production of new varieties of maize is being done or visit to a local beer brewer to see how biotechnology is applied. Use of resource person: who is knowledgeable on issues of biotechnology carried out in his area of specialization	Discussions: learners discussing the materials required for genetic engineering Explanations: learners/ teacher explaining the process of genetic engineering Questions and answers: where learners will be involved to give responses posed to them by the teacher or fellow learners.	Discussi learners asked to the prod insulin. Brainsto will be a brainstor applicati biotechn
Specific ways of ascertaining students' understanding or confusion around	Students giving - The meaning of biotechnology	Students providing examples of new poultry breeds (black australope), hybrid seeds available in	Students to come up with tools used in genetic engineering;	Students in detail applicati biotechn

this idea (include likely range of responses)	- Examples of biotechnology they know	Malawi such as Kanyani, Msunga banja and DK 9089 among others.; cross breeding Malawi Zebu with exotic breeds to come up with breeds which can give more milk and meet.	The process of genetic engineering in detail	as in me agricultu industrie cleaning managin environn using th fungi an used to b toxic sul

Appendix M: Content Representation (CoRe) for John for teaching Biotechnology topic

	Big Science Ideas/Concepts			
	A. Historical outlook of biotechnology	**B.** Plant and animal breeding	**C**. Genetic engineering – from DNA to recombinant proteins	**D**. Biote applicati drugs an producti
What you intend the students to learn about this idea	Students should know the background of biotechnology. When biotechnology stated When it was discovered	Cross breeding can take place in plants and animals. In plants, indigenous and exotic breeds can be crossed likewise animals.	How new genes are formed by modifying of DNA of an organism to produce new genes with new characteristics. Gene probe	Treatme multiple like scle cancer, l and anae Also use vaccines provide effective against I Also, the of protei
Why is it important for students to know this?	For easy understanding of the topic	To know how hybrids are formed	For students to know and apply in real life situations	To impr health o organism

What else do you know about this idea (that you do not intend students to know yet)?	DNA code, bases forming the DNA like Adenine, Guanine, Uracil, Thymine, and Cytosine	Exotic breeds can be crossed, indigenous breeds can also be crossed depending on desired characteristics	Making connection of genetics of mice and human beings. The polymerase chain	Can be a agricultu
Difficulties/limitations connected with teaching this idea	It can not give valid information as biotechnology started a very long time ago	Easy to transfer diseases. Gene pool	Can transfer genes that can cause a certain effect than preventing	Causing BP, Hea
Knowledge about students' thinking which influences your teaching of this idea	The learning process can be faster as well as the teaching process because they already have knowledge from agriculture	Some students think that DNA is found in animals only and not in plants. Need for emphasis	Some students think that DNA is found in animals only and not in plants. Need for emphasis	They thi products biotechn is, food easily ca
Other factors that influence your teaching of this idea	My prior knowledge of other subjects. It's easy to teach as I also teach cross breeding in agriculture.	It's easy to teach as I also teach cross breeding in agriculture. Also the knowledge of selecting seeds for	Knowledge gained from college	Knowled producti in agricu

	Also, the knowledge of selecting seeds for planting from ancestors	planting from ancestors		
Teaching procedures (and particular reasons for using these to engage with this idea)	Inform students when biotechnology started. Knowledge of ancestors Recent knowledge	Have local and exotic plants and cross them. Have local and exotic animals and cross them	Isolate the gene. Insert in a host. Produce as many copies of the host as possible.	Have a f How pla genes
Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses)	Formulating questions or making a survey	Students discuss and the teacher listens attentively	Doing experiments	Doing ex Food tec

Appendix P: Content Representation (CoRe) for teaching Biotechnology topic (Under Core element: Genetic and Evolution)

	Big Science Ideas/Concepts				
	A. Historical outlook of biotechnology and definition	B. Plant and animal breeding	C. Genetic engineering (from DNA to recombinant proteins)	D. Biotechnological applications towards drugs and food production	E. Ethical implications of biotechnology
What you intend the students to learn about this idea	Biotechnology is the use of living organisms and their body systems to develop new and useful products that help to improve human life.	I intend to teach students how artificially plants and animals are bred.	Students must know that genetic engineering is also called recombinant DNA technology. Students must know the process of	I intend to teach students about the application of biotechnology in (1) medicine which is the	Students should be able to explain the benefits of biotechnology

	Biotechnology was used by our parents in cases of brewing beer, baking bread and even artificial selection of seeds to plant or animals to breed before we started learning about it in schools		genetic engineering, that is step by step using an example of B-cotton variety	production of pharmaceuticals using microorganisms such as bacteria and fungi; the gene therapy which is the use of nucleic acids in drugs to treat diseases e.g cancer. (2) application in industries such as the manufacturing of detergents, enzymes, beer and	such as the provision of high-quality hybrids of plants and animals, the production of proteins in plants and animals for various nutritional values and to the treatment of various disorders in

				bread apart from sewage treatment. Students must understan d that in manufactu ring industries, microorga nisms are used. (3) Applicatio n in agriculture . Students must know what transgenes or geneticall y modified organisms are and how bacteria are used to	animals and plants such as human insulin among other benefits . Howev er, they should also be able to explain the proble ms associat ed with biotech nology. These include the miscon ception s that genetic ally

				produce a synthetic bovine somatotropic hormone that is injected into cows to increase milk production	modified organisms and food may be dangerous to the consumers; transgenic plants may affect other related species thereby interfering with the ecosystem; alteration of genetic codes of organis

					ms may lead to undesir able mutatio ns that may cause disorde rs and disease s to the organis ms concern ed among other proble ms
Why is it important for students to know this?	Knowledge of the biotechnology definition and the examples of biotechnology activities which were done by our parents and the plant and animal breeding	This is important because as populations are increasing, food production must increase also and this is being done using biotechnology techniques. High-yielding	Without the knowledge of the genetic engineering process, students cannot understand how it takes place and why it is	Once students understan d the production process of human insulin, they can easily describe	A lot of things are being said about biotech nology. Some things are

	being done in Malawi will help them understand the other concepts they will learn.	and resistant varieties are being produced through biotechnology in both plants and animals.	important. Knowing the process, students can easily apply what they learn in everyday life.	and explain how other hormones, enzymes, proteins and other products are produced where microorganisms like bacteria are used.	beneficial while other things have disadvantages. Therefore, if students could understand these ethical issues, they could be able to teach others about the misconceptions about biotechnology
What else you know about this	The detailed history of biotechnology	Detailed processes of artificial	What students are supposed to learn is	I know different apparatus	There are many

idea (that you do not intend students to know yet)?		breeding of different plants and animals	about the general process of genetic engineering. I know more about different forms of genetic engineering which students are not supposed to know	or equipment and some chemicals used in insulin production	benefits of biotech nology and there is no way I could teach everyth ing and also miscon ception s are many which you can not teach the student s as you have to follow the curricul um
Difficultie s/limitatio ns	This content depends on the understanding	As the curriculum suggests a	The process is discussed using charts/	The process could only	Student s have heard

connected with teaching this idea	of students on reproduction, different diseases especially those which need vaccines and antibiotics and genetics	discussion of plant and animal breeding makes the teaching not interesting to students	animations where computers and electricity are available without the actual experiment.	be animated where ICT is available, however, a theoretical approach is likely to be used	many scientifi c issues related to biotech nology and have many miscon ception s on, howeve r, as a few things are taught, some student s leave the school with some miscon ception s about areas not

					taught in class
Knowledge about students' thinking which influences your teaching of this idea	Students take this topic as a new concept that they have not learnt before either in biology or other subjects like agriculture	Students may think that the topic is difficult as it is under the core element "Genetics and Evolution" and the students also may not be aware of many applications of biotechnology	Students are not aware of the whole process of genetic engineering	Insulin use in the human body is not new as the students learnt already about diabetes and the effect of underproduction of insulin	As many students are not aware of many technologies available, it is my duty to teach them and ask many questions so that they understand the ethical implications available

Other factors that influence your teaching of this idea	Students like to learn about inheritance	The genetics content may assist students to understand some of the applications of biotechnology	The knowledge of the structure of chromosomes, DNA and gene enables students to understand the process of genetic engineering.	Knowledge of bacteria structure and their reproduction; how enzymes work and how different are they from hormones.	Meaning of the term ethics should be well understood by the students so that they are able to discuss different ethical implications of biotechnology
Teaching procedures (and particular reasons for using these to engage with this idea)	This serves as the basis for class discussion about what is known/not known about biotechnology Question Building Through discussion: Students explain to each other (in pairs) what each	Explanation: Students describe examples of plant breeding such as hybrid seeds production, production of varieties of poultry and production of cattle apart from what they know already like bread	**Question and answer** will be used as an introduction. They have to define what genetic engineering is. **Using animation**, let	Students are provided with textbooks. **Question and answer**; Before going into	The different ethical implications of biotechnology provided in the differen

	knows about biotechnology and develop a list of activities done in biotechnology. The pairs then present to the whole class what they discussed	baling and beer brewing. The class, in small groups develop an explanation of plant and animal breeding	them watch what is happening and let them discuss what was happening **in pairs** in the example of genetic engineering. Sample a few pairs and let them present what they observed. I would come in and clarify the steps or stages which are not clear in the process of genetic engineering.	groups, students are asked about different applications of biotechnology they are aware of and ask them to explain how they work. Later**, in groups,** let them refer to the textbooks and identify different applications discussed and let them present what they	t student textbooks should be discussed. Some will be discussed using **group work**, some by **debate,** and some of them in **pairs** until all of them are exhausted.

				have found in different textbooks provided. Review the previous lesson with **questions and answers**. Review again the functions of insulin in the human body, where it is produced and what effect it has when there is underproduction of insulin**.** **Using a**	

				chart, discuss how insulin is produced. Using the steps of genetic engineerin g, students should be able to follow the process of insulin production .	
Specific ways of ascertaining students' understandin g or confusion around this idea (include likely range of responses)	Use questioning technique. Students give different definitions of biotechnology. I come in with a specific definition or definitions as outlined in student textbooks.	Use questioning technique, observation as students discuss in either groups or pairs give examples of poultry breeding; production of hybrid seeds and be able to give specific examples of maize seeds such	After discussing the process of genetic engineering, let the students describe the process in their own words if they can or use what was used	At the end of the lesson, ask the students many descriptiv e questions on what they had learnt on applicatio ns of	As each and every ethical issue is being discuss ed or debated , ask questio ns to ensure that

		as DK 3790, etc. and production of hybrid cattle as the same content is taught in agriculture	by the teacher.	biotechnology. As they state the applications, let them describe how biotechnology is applied. Before, introducing the production of insulin process, give students a quiz on what they had learnt previously and after teaching them about the process of insulin production	students understand the implications of biotechnology.

				, ask them questions on the stages or steps of insulin production and in concluding ask them to describe the whole process and check if anyone student has a problem.	

Appendix Q: Guidelines for scoring components of TSPCK - based on CoRes

PCK components	(1) Limited	(2) Basic	(3) Developing	(4) Exemplary
Curricular Saliency	-Identifies subordinate ideas and pre-concepts are a mix with those of other topics or no subordinates provided. -Sequencing no value due to mixed concepts. -Reasons given for the importance of the topic limited to the general benefit of education -Inaccurate content or misunderstandings of big idea -Possible sources of confusion not identified	-Not all 5 Big Ideas have subordinate concepts identified however those identified are correct. -Sequencing can be followed, however, has one illogical placing of key concepts (Big Ideas) and also for the suggested preconceptions -Reasons given for the importance of the topic exclude conceptual considerations such as scaffolding/sequential development of understanding for other topics in the subject. -Knowledge is often limited to what students need to know	-Identifies correct subordinate's ideas and shows links to Bid Ideas with no additional explanations -Provides a logical sequence of concepts of some of the Big Ideas within reason -Identified pre-concepts includes those used in the definition of the current topic -Reasons given for the importance of topic include reference to conceptual scaffolding/sequential development of understanding of other topics in the subject without specifying the topics -Research evidence, demonstrates a sound understanding of topics beyond what students need to know. -Identifies possible sources of conceptual confusion at a surface level.	-Identifies correct subordinate ideas and explains links to Big Ideas. -Provides logical sequence of concepts of all the Big Ideas and pre-concepts of all the Big Ideas and pre-concepts logical within reason -Identified pre-concepts include those needed in discussing the introductory definitions and those sequentially needed in the next Big Ideas of the current topic. -Reasons given for the importance of the topic include conceptual scaffolding/sequential development of understanding for specified subsequent topics in the subject. -Comprehensive, well organised knowledge of topics;

		-Possible sources of confusion not identified		foregrounds main ideas; networked examples -Identifies possible sources of conceptual confusion.
Student prior knowledge including misconceptions	Not perceptive of students' needs/ No identification, acknowledgement/ No consideration of students' prior knowledge or misconceptions.	-Identifies misconception or prior knowledge on one big idea only -Aware of students' needs but not able to find the appropriate balance	-Identifies misconception or prior knowledge on two or more big ideas. -Provides the basis and reasons for the consistent students' knowledge. -Aware of students' needs; consider their context and diversity	-Identifies misconceptions or prior knowledge of all Big Ideas. -Provides the basis and reasons for the consistent students' knowledge. -Identifies and considers diversity in students' ability, learning style, interests, developmental levels and needs. -Confronts misconceptions/confirms accurate understanding A subtle understanding of student strengths and weaknesses
Representation explicitly in CoRes	Limited to use of analogies, demos, etc. representation with no explanation of specific links to	-Describes or demonstrates ways to model or illustrate a concept (analogies, demos, diagrams etc) and use of	-Describes or demonstrates ways to model or illustrate a concept (analogies, demos, diagrams, etc) and use of representation with	-Describes or demonstrates ways to model or illustrate a concept (analogies, demos, diagrams, etc) or symbolic representation and

	the concepts represented	representation without explanatory notes to make the links to the aspects of the concept being explained (For only one big idea)	explanatory notes linking the two representations to the aspect(s) of the concept being explained (For more than one big idea)	- Use of detailed representation to enforce a specific aspect(s) of the concept being explained
What makes topic difficult	-Leaves black spaces, reasons not given -Identifies broad topics without specifying the actual sub-concepts that are problematic	-Identifies only the contextual constraints -Identifies broad topics without specifying the actual sub-concepts that are problematic.	Identifies specific concepts with reasons related to specified prior knowledge of students or common misconceptions for at least one big idea	Identifies specific concepts with reasons related to prior knowledge of specified students or common misconceptions for more than one big idea.
Teaching strategies (in, about, for)	-Provides no evidence of acknowledgement of student prior knowledge and misconceptions. -Lacks aspects of curriculum saliency (e.g. corresponding subordinate concepts in a topic, sequencing for scaffolding learning, awareness of the background concepts needed	-Acknowledges student misconceptions with no corresponding confrontation strategy -Lacks aspects of curriculum saliency. -Uses a few T/L strategies with little variation hence limited involvement of students as students are given tasks that develop recall.	-Overall, the strategy is workable. -Considers confirmation/confrontation of student prior knowledge and/or misconceptions. -Considers at least one aspect related to curriculum saliency: sequencing or what not to discuss yet or emphasis on important concepts. -There is evidence or encouraged student involvement; experiments with a variety of T/L strategies hence	-Overall, excellent strategy to teach a required concept. -Considers confirmation/ confrontation of student prior knowledge and /or common misconceptions. -Considers at least two aspects related to curriculum saliency: sequencing, what not to discuss yet, the emphasis on important conceptual aspects, etc -Provides justification for the

	before teaching the topic) -There are few opportunities for student development; suggested activities are largely teacher centred -Justification for choice of teaching strategy not provided	-No justification for the choice of teaching strategy.	students given comprehension or application tasks.	choice of teaching strategy consistent with biotechnology specific strategies. -Highly student-centred lesson; thoughtfully selects and effectively uses a variety of T/L strategies appropriate to the content and students.

Adapted from Mavhunga & Rollnick (2011) and Mphathiwa (2015)

Appendix R: Part of Joseph's first transcribed lesson

Teacher: Good morning, class.

Class: Good morning, Sir.

Teacher: The day's lesson will be on Biotechnology, and the topic is not new; you have heard it. Here are two packets of hybrid maize, these are products of biotechnology, and the eggs you buy from the markets and different animal products are produced by biotechnology. From the given examples, what do you think is the definition of biotechnology? What is biotechnology?

Student: It is the process of changing some existing organisms to become one with an aim of improving products.

Teacher: What about others, what do you understand by the term biotechnology?

Student: It is the process of reintroducing of some varieties to come up with desirable characteristics.

Teacher: These two definitions are very close to the correct definition. (The teacher writes on the board his definition as follows). Is the use of living organisms and their body systems to develop new and useful products that help to improve human life. [The teacher compares his definition to what students had given.

Teacher: "Biotechnology involves the use of genetic engineering the system of biotechnology it uses the technique called genetic engineering so under this they try to change the DNA molecule in a biological term is called recombinant DNA. Have you ever heard about recombinant DNA? Ok so it's something new. (All students are quite)

Teacher: A recombinant DNA simply means that DNA that contains different DNA, they take DNA from one organism and DNA from another organism, they join together, they combine together to make a new DNA, that means this DNA will contain information from two organisms. So that kind of DNA coming from different organisms is called Recombinant DNA. *{Then the teacher writes on the chalkboard as follows: The technique involves genetic engineering where they alter DNA molecule (Recombinant DNA) can be* *used to produce characteristics of a given factor required when incorporated in the microorganism.}*

Teacher: Did I say the meaning of recombinant DNA? What is recombinant DNA?

Student: This is the DNA that contains different DNAs from different organisms

Teacher: (***Writes on the chalkboard)*** Recombinant DNA is the ability to combine the DNA of one organism with the DNA of another organism. Genetic engineers can alter the DNA code of living organisms. Now the question is what do they use to alter the DNA if they want to turn the DNA of another organism. In the definition, I said that it is the ability to combine the DNA of one organism with the DNA of another organism, but in the systems of using that, they use some microorganisms. They use what?

Students: (*in chorus form they answer*) Microorganisms.

Teacher: Can you suggest which microorganisms they can use to come up with recombinant DNA which they can use to multiply these microorganisms.

Student: Bacteria

Teacher: Yes true, they mostly use bacteria and viruses. {*on the chalkboard he write: bacteria and fungi are used to produce eukaryotic proteins}*

Teacher: We have to look at some terminologies as far as biotechnology is concerned. Now, lets try to look at some examples of plant and animal breeding in Malawi, in our country. What could be some examples of plant and animal breeding which could be in line with biotechnology.

Teacher: (*writes the title: Plant and Animal Breeding in Malawi*). As I said, I brought you some examples so that you can appreciate, I said this is an example of what, plant or animal?

Students: (*in chorus form)* Plant

Teacher: They only breed plants or animals with desirable traits. What do we mean by desirable traits? Share with your friend or neighbour, may be your neighbour may have an idea. I think you have come up with something. In genetics, we looked at traits, what does that mean?

Student: Characteristics

Teacher: So when we say desirable traits, what do we mean?

Student: desirable characteristics

Teacher: Why biologists or scientists coming up with breeding system? What made them or inspired them to start coming up with breeding system? Do think they just sat down and today will start breeding? What do you think are some of the reasons which inspired them to start breeding system?

Students: (in chorus form) No

Teacher: Yes, there is only Gerald, what about others, lets share ideas, Yes Gerald

Student: May be because of harsh, change of climate

Teacher: He is saying this made them to do so because there is change in climate. That's one which made them to start breeding. Another one, yes

Student: In order to come up with high yielding breeds

Teacher: All those are reasons, but apart from climate change, another reason was the growing population, there was a growing demand for food. There was demand for..

Students: Food

Teacher: So they were trying to say the growing population is in need of food but the supply is low that's why they come up with breeding systems to accommodate the growing population (writes on the chalkboard {*Why breeding: - Demand for food with growing population*}

Teacher: Let's start with examples of plant breeding in Malawi, the title is plant and animal breeding in Malawi. Let us start with examples of plant breeding in Malawi. Do you know any examples of plant breeding in Malawi, Yes

Student: Varieties of different seeds. Right, what are some examples of plant seeds that know.

Student: Maize seeds, 407,

Teacher: Which company makes that one?

Student: Seedco.

Teacher: Any traditional language the local one, is it Kanyani, Njovu.

Student: SC403

Teacher: Is it Seedco?

Student: Yes, it is Seedco.

Teacher: Ok in here I brought these two, this is seedco and DK777, this one is Mosanto and this one is SC403 which is Kanyani in our local language. Alright. So indeed one of the example we can talk about is Maize, but another one is BT cotton. And this BT cotton was produced by the Lilongwe University of Agriculture and Natural resources, LUANAR, was made by these people BT cotton. You know what LUANAR. You do better you go to LUANAR, there is campus of NRC and Bunda, so it means you will among if you study the area of agriculture, you can among, changing or bring other varieties of crops like what the college did here coming up with another variety which is BT cotton and this cotton produces yield twice as much compared to available variety. They say it produces more than twice, so it means this one is very nice. Ok, so another example you have already mention is about hybrid produced by Mosanto and Seedco. Then what you must understand is that the examples I have given you is about hybrid. So for one to be called a hybrid, what is a hybrid? A hybrid is formed by what?

Appendix S: Part of James' first transcribed lesson

Teacher: good afternoon class

Students: Good afternoon, Sir

Teacher: Sit down, thank you.

Teacher: Drew lines on the chalkboard to divide the chalkboard into 3 parts.

In the last lesson, on Genetics, we looked at and defined what genetics is, and also we looked at the causes of variations. What did we say what is aaa what is what about variations and also about we looked at types of variations. Can you give me the types of variations we learnt at that time. Types of variations

Student: Continuous variations

Teacher: continuous variations and

Student: Discontinuous variations

Teacher: In this one, can you give me any two examples of continuous variations? Any two examples of continuous variations. Yes

Student: Height

Teacher: Height, two

Student: Weight

Teacher: Height of what and weight of what?

Student: Height of an organism

Teacher: Example of an organism would be?

Student: Human being

Teacher: The human being, a very good example and in this class, we can measure

Student: Skin colour

Teacher: Skin colour, where? In Goat or what?

Student: Body of humans

Teacher: Body of humans OK, thank you so class that's what we discussed last time. Today we are going to look at a new topic. This new topic is on biotechnology (Writes the title on the chalkboard). This is our topic that we are going to look at today. AAA, Biotechnology, may be you have heard about the word biotechnology. Have you heard about the word biotechnology? Have you ever heard about the word biotechnology?

Students: in a chorus form Yes!!!

Teacher: So, can you think, can you think what is biotechnology? What is biotechnology? Some of you have said you have ever heard about it; what does biotechnology mean? Gabriel

Student: It is the study of organisms using genetic engineering

Teacher: That's what Gabriel said, it is the study of organisms using genetic engineering. Others, Others? Rashida help us, what does biotechnology mean? Yes no idea, Ok who can come to her rescue?

Student: The technology, the techniques that are applied to organisms in order to produce a desirable characteristics of an organism.

Teacher: Again

Student: The techniques that are applied in order to produce the desirable characteristics of an organism

Teacher: Thank you. Sorry I forgot to write your answer. (Writes both answers on the chalkboard). Any other addition. Ok, so these are some of ideas from our friends. Say the study of organisms using genetic engineering and then he says a technique used to produce desirable characteristic of an organism. You will see that may be there are some other similarities in the answers you have provided. But in short let's look in summary when you are looking at biotechnology is. Biotechnology is the utilization of the organisms or part of the organism or their processes to produce either living organisms or to produce things for human benefit. (Repeats the answer: Then writes the definition on the chalkboard as follows: Utilization of organisms, part of the organism and the biological processes for human benefit. *{However, the teacher gives or writes only one definition leaving out one written on his lesson plan}*

Teacher: so we are going to continue and we will be into groups. Asks the students to go into their groups. We are having 6 groups, isn't? So let's go into our groups, quick. Asks members from the groups to go in front and collect materials. (These are textbooks, photocopied pages of the topic from a textbook in short supply and a worksheet with questions plus a chart and a pental pen instructs the students to follow the worksheet provided and tells them the activity will take about 15 minutes.

(In their groups were reading the answers from the textbook and the photocopied pages from a textbook in order to answer the first question and as the students were reading and discussing the activity, the teacher was going round the groups and in some cases, the teacher was able to assist the learners)

Teacher: Those groups which have finished, please paste the charts on the chalk. (Groups 1, 3 and 2 pasted their charts and the teacher asked group 1 to make a presentation)

Teacher: For the interest of time, the other groups will continue making their presentations in the next class so that we can hear their side of the story so only these two groups will present today.

Student from group 1: We were given that we should discuss the places in Malawi where the production of high breed seeds in done. The high breed seeds is produced by the following companies. a. is Mosanto, they produce the seeds like Pan 3434 DK9039 and the other company is Panner. Production of poultry varieties. These are produced by the hybridization of poultry such as kasinaga, tsumba and kameta. Places where production of chickens in done . Mikolongwe breeds production. They crossbreed local breeds and exotic such as the high lines and kaluka. And the last one is production of dairy cattle. The place is Lilongwe Dairy Board and this company breeds the Malawi zebu with the exotic such as Huseni and tesy.

Teacher: That's the presentation from group number one. Any observations? Any observations from the presentation of group number one? Yes

Student: Question. Where is Mosanto company.

Student from group 1: I think it is in Lilongwe, but am not sure.

Another student answer on behalf of the presenter: It is in Lilongwe, Kanengo

Teacher: Asks the class to clap hands for the presenter.

Teacher: So for interest of time, so for groups 3,and 4, 5 and 6 will conclude their presentations, may be in the next lesson, but in conclusion, the production of hybrid seeds in Malawi is done in so many areas, so many companies they have farms and they are producing hybrid seeds. Already examples are the ones which group 1 have already done like Mosanto which produces these varieties of maize seeds and also we have Chitedze Research station which is just along the Mchinji road. They also produce varieties of hybrid seeds and the main reason for producing these seeds, maize varieties which are either early maturing which can produce for yields in a small area. But also production of these hybrid seeds which can survive in the conditions of that particular area. So, these are all done in order to benefit humans which could be using these varieties. So most of these are done in order to replace the local varieties because right now they are not doing better with the conditions Malawi is experiencing right now.

Production of poultry, yes, so the production of aaa, the breeding of poultry, the areas where breeding of poultry is done, of course we have got Mikolongwe where they do cross breed the local varieties of poultry with the exotic ones. For example, the most commonly used is the black astrop which is cross breed with the indigenous chickens. They have given examples of tsumba, and kameta. These are local varieties which are cross breed with the exotic ones. The main reason there is that traits which are good characteristics from the black astrop. When you look at the black astrop, you will see that it is big, it means it has a lot of meat, it also produces a lot of eggs. But our local chicken is very thin, but the advantage of this local variety is that it is able to resist some of the diseases and conditions that we have in Malawi. So when you cross breed you are going to get the advantages of the local and the exotic one so that you produce a chicken which is able to give us a lot of meat and also a lot of eggs. **Are we together?** This is what is done at Mikolongwe

Appendix T: Part of John's first lesson transcribed

Teacher: greets students and introduces the lesson by telling the students the topic of the day, Biotechnology. (He writes on the chalkboard, Biotechnology)

Teacher: Biotechnology is made up of two terms "Bio" and "technology" and asks the students the meaning of Bio

Student: Bio means life

Teacher: Very true and what about technology, how can you define technology

Student: New skills passed from one generation to another

Teacher: He says new skills passed from one generation to another. What is technology? yes

Student: Technology means scientific knowledge (skills) but we are using it in life.

Teacher: (The teacher repeats what the student stated) technology means scientific knowledge, scientific skills, but we are using in life. Something that is living. (writes on the chalkboard: Technology = scientific knowledge

Teacher: Biotechnology is used interchangeably with Recombinant DNA {Write on the chalk board the statement}. Recombinant DNA is the ability to combine DNA of one organism with DNA of another organism. It means a new organism will be formed by combining DNA of one organism with DNA of another organism. But first of all, before I could talk about Recombinant DNA, what do you know about hybridization? (Writes on the chalkboard) repeats the question. Or what happens in hybridisation?

Student: It is when cross breeding is done in plants or animals

Teacher: There is cross breeding in plants or animals (writes on the chalkboard and repeats the statements). There is cross breeding in plants or animals

Teacher: what is the main aim of crossing in plants or animals? The aim of why you can cross plants or animals

Student: The aim is to come up with new organisms.

Teacher: Repeats what the student has said and writes on the chalk board [so the aim is to come up with new organism,], that's what happens in hybridisation. For example, who can give an example, you can take [stops and asks a student to give the example]

Student: You can take a Malawi zebu and a Fresian cattle and cross them

Teacher: You can take exotic and indigenous cattle and cross them in order to come up with an improved breed, to come up with an improved breed, eti?

Students: Yes {in a chorus form}

Teacher: Its just the same with AA!! so that happens in hybridisation is also what happens in genes. When you want to improve an animal, you can take genes from one organism and take those genes, the DNA, from one organism to another, what?

Students: (In a chorus form): Organism

Teacher: So as to improve this one because the new organism which has been injected with the DNA of the other organism, now this new DNA will start functioning in this one, you see, that is one way of improving such organisms. It was first used in 1970s. Biotechnology was first used in 1970s with bacteria. it means they wanted to improve the activities of what?

Students: Bacteria {Chorus form}

Teacher: Bacteria. But now it can be used to improve different organisms, even in agriculture to come up with better breeds, of cattle, better breeds of goats, sheep, pigs, different animals, but also in plants apart from animals. For example the maize plants. When you hear about DK, DK what?

Student: DK 8031

Teacher: DK8031, eti? It means they have come up with improved what? Maize varieties by gene recombinant. We are together? [First time to ask them] So they alter the DNA code of an organism. {He writes on the chalkboard}. To alter is to change, an organism has its own DNA, but they alter it, they change by introducing a new kind of what?

Students: Organisms

Teacher: By introducing a new DNA code. Can someone give me the full name of DNA

Students: Yes

Teacher: who can tell us, what is DNA in full?

First Student: Deoxygenribo…..(First student fails to pronounce the term.)

Second student: Deoxyribonucleic acid

Teacher: Deoxyribonucleic acid, DNA

Teacher: Where is DNA found?

Student: In the nucleus

Teacher: It is found in the chromosomes and chromosomes in the nucleus. You know the nucleus controls all the activities of the cell, but the nucleus contains chromosomes, now the chromosomes there is DNA there, on DNA there are some genes there eti? That control certain characteristics, which are these characteristics which are controlled by genes on the DNA?