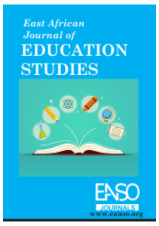

East African Journal of Education Studies
eajes.eanso.org
Volume 8, Issue 1, 2025
Print ISSN: 2707-3939 | Online ISSN: 2707-3947
Title DOI: https://doi.org/10.37284/2707-3947

EAST AFRICAN NATURE & SCIENCE ORGANIZATION

Original Article

Investigating Biology Teachers' Topic-Specific Pedagogical Content Knowledge Components Used in the Teaching of Biotechnology. The Case of the Central West Education Division in Malawi

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Article DOI: https://doi.org/10.37284/eajes.8.1.2604

Date Published:

11 January 2025

Keywords:

Biotechnology, TSPCK, Students' Prior Knowledge, Curriculum Saliency, Content Representation, Instructional Strategies.

ABSTRACT

This study investigated biology teachers' topic-specific pedagogical content knowledge (PCK) components used in teaching biotechnology. It focused on four key objectives: (1) identifying instructional strategies specific to biotechnology, (2) assessing teachers' awareness of students' prior knowledge of the subject, (3) examining teachers' knowledge of content representations, and (4) exploring curriculum saliency. The study adopted an interpretive paradigm to capture teachers' experiences with biotechnology instruction. A case study design was used, following a qualitative research methodology. The sample consisted of three biology teachers from different secondary schools, each teaching biotechnology in form four classes. Data were collected through content representations (CoRes), interviews, and lesson observations, with document analysis of curriculum materials employed to triangulate findings. The results revealed that biology teachers faced challenges in connecting biotechnology concepts with students' prior learning, particularly in genetics and reproduction. Additionally, teachers exhibited limited familiarity with instructional strategies tailored to biotechnology. The study highlighted a reliance on textbooks for both content and teaching strategies by the teachers. However, the study noted that some textbooks lacked the necessary illustrations and activities to promote critical thinking. The effective teaching of abstract biotechnology concepts requires a solid application of topic-specific PCK components. Teachers must demonstrate several components of topic-specific pedagogical content knowledge in the teaching of biotechnology which includes the history of biotechnology, ethical considerations, and argumentation skills. The study recommends that curriculum developers ensure textbooks contain comprehensive content, including clear illustrations and activities aligned with the syllabus, to better support teachers and students in understanding and applying biotechnology concepts effectively.

APA CITATION

Vakusi, G. M. & Mbano, N. (2025). Investigating Biology Teachers' Topic-Specific Pedagogical Content Knowledge Components Used in the Teaching of Biotechnology. The Case of the Central West Education Division in Malawi. *East African Journal of Education Studies*, *8*(1), 237-253. https://doi.org/10.37284/eajes.8.1.2604

CHICAGO CITATION

Vakusi, George Macdonald and Nellie Mbano. 2025. "Investigating Biology Teachers' Topic-Specific Pedagogical Content Knowledge Components Used in the Teaching of Biotechnology. The Case of the Central West Education Division in Malawi". *East African Journal of Education Studies* 8 (1), 237-253. https://doi.org/10.37284/eajes.8.1.2604

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HARVARD CITATION
Vakusi, G. M. & Mbano, N. (2025) "Investigating Biology Teachers' Topic-Specific Pedagogical Content Knowledge Components Used in the Teaching of Biotechnology. The Case of the Central West Education Division in Malawi", *East African Journal of Education Studies*, 8(1), pp. 237-253. doi: 10.37284/eajes.8.1.2604

IEEE CITATION
G. M., Vakusi & N., Mbano "Investigating Biology Teachers' Topic-Specific Pedagogical Content Knowledge Components Used in the Teaching of Biotechnology. The Case of the Central West Education Division in Malawi" *EAJES*, vol. 8, no. 1, pp. 237-253, Jan. 2025. doi: 10.37284/eajes.8.1.2604.

MLA CITATION
Vakusi, George Macdonald & Nellie Mbano. "Investigating Biology Teachers' Topic-Specific Pedagogical Content Knowledge Components Used in the Teaching of Biotechnology. The Case of the Central West Education Division in Malawi". *East African Journal of Education Studies*, Vol. 8, no. 1, Jan. 2025, pp. 237-253, doi:10.37284/eajes.8.1.2604

INTRODUCTION

Malawi is striving to keep pace with global advancements as the world enters the Fourth Industrial Revolution (National Planning Commission, 2021). A key area of focus in this era is biotechnology, which is a rapidly expanding field of scientific and public interest. Many countries, including Malawi, have integrated biotechnology themes into secondary science curricula (Hanegan, & Bigler, 2009). Thus, biotechnology is important for students to understand due to its potential to significantly impact individuals and society at large (Moreland et al., 2006).

The Office of Technology Assessment (OTA) in the USA (1988, p. 1991) defines biotechnology as "any technique that uses living organisms (or parts of organisms) to make or modify products, improve plants or animals, or develop microorganisms for specific purposes." This widely accepted definition forms the foundation for biotechnology education in academic institutions and industries (Dunham et al., 2002).

Biotechnology educates students about using living organisms and biological processes in medicine, engineering, technology, and other fields (Srutirupa, & Mohalik, 2013). This includes genetic modification, which involves transferring genetic material between organisms—whether plants, animals, or microorganisms (Barış, & Kırbaşlar, 2015). Modern biotechnology continues to drive advancements in crop production, food development, and pharmaceuticals (Cavanagh et al., 2005). However, despite its contributions to agriculture, industry, and biomedicine, biotechnology has sparked ethical debates, particularly around genetically modified organisms (GMOs) and human gene cloning (Fonseca et al., 2012). Consequently, teachers play a crucial role in promoting biotechnology education and ensuring that the public is well-informed (Fonseca et al., 2012). Teachers also significantly influence students' understanding of biological concepts (Mapulanga, & Chituta, 2018).

While many developed countries began offering biotechnology education in secondary schools over 20 years ago (Kidman, 2009), Malawi and other developing nations have only recently incorporated biotechnology into their science curricula. This integration reflects a growing recognition of biotechnology's potential in various industries. Despite the importance of biotechnology in both science and education, research on biotechnology education remains limited (Borgerding et al., 2013). A study conducted in Turkey by Gul, & Sozbilir in 2015 found that most research on biology education focuses on topics like ecology, genetics, and animal form and function, with limited attention paid to biotechnology. Research in biotechnology education primarily examines attitudes and interest in the field (Fernandez, 2014). In Malawi, perhaps, because biotechnology is a new and potentially challenging subject, no research has yet determined if students indeed find it difficult (Ministry of Education, 2018).

One of the major challenges for teachers is effectively delivering biotechnology content (Naz, 2015). Teachers must navigate what knowledge and ethical issues should be taught (Kidman, 2009), as biotechnology involves complex and rapidly evolving information. In addition to content challenges, teachers face limitations in infrastructure, qualifications, experience, and access to professional development. The biology curriculum envisions secondary school graduates with a basic understanding of plant and animal

Article DOI: https://doi.org/10.37284/eajes.8.1.2604

breeding strategies, genetic engineering, as well as applications of biotechnology in medicine, agriculture and other industries. Under genetic engineering, students should learn about recombinant DNA technology used in many applications such as insulin production, and Genetically Modified Organisms (GMOs) among other applications. Apart from studying the concepts, students are also required to be aware of ethical implications and misconceptions about biotechnology and its applications in the real world to minimise misconceptions people have about biotechnological applications (MoEST, 2013). Many lack the teaching skills and competence required to address biotechnology topics effectively. As the curriculum encourages using ICT in teaching biotechnology, teachers who lack computer skills may struggle to implement this aspect of instruction.

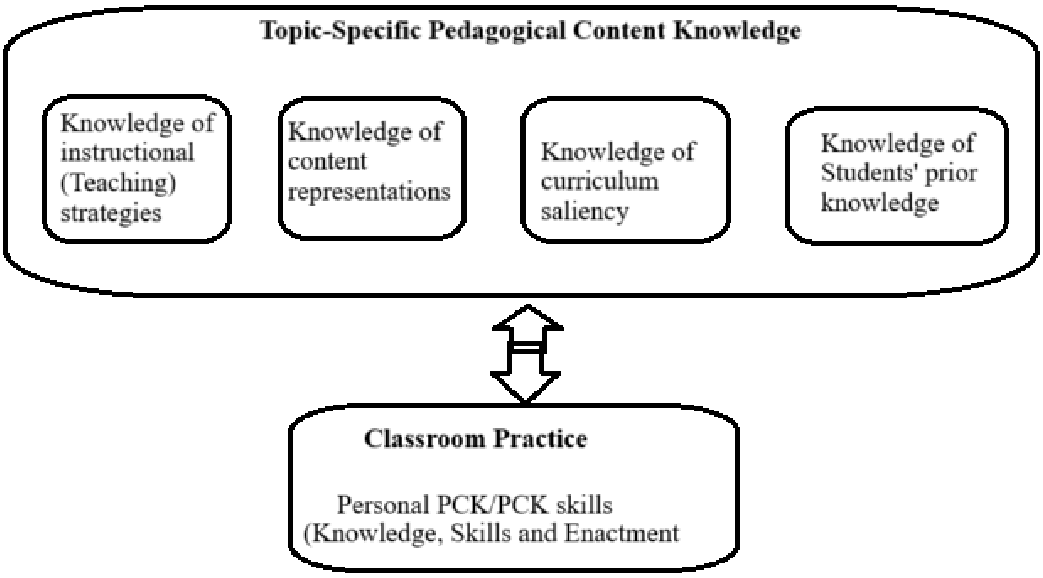
The purpose of this study was to investigate the topic-specific pedagogical content knowledge (TSPCK) components utilised by secondary school biology teachers in the teaching of biotechnology. The study was guided by the following objectives:

- What is the level of biology teachers' knowledge of instructional strategies for teaching biotechnology?
- What is the level of biology teachers' knowledge of students' prior knowledge regarding biotechnology?
- What is the level of biology teachers' knowledge of the biotechnology curriculum?
- What is biology teachers' content representation in the teaching of biotechnology?

LITERATURE REVIEW

Conceptual framework

Figure 1: **A Conceptual Framework for the Study**



The conceptual framework for this study (Figure 1) is based on the Consensus Model by Gess-Newsome (2015). The analytical framework is largely derived from this model, particularly its description of topic-specific professional knowledge (TSPK), also referred to as topic-specific pedagogical content knowledge (TSPCK). The framework focuses on key components such as knowledge of content representation, student prior knowledge, instructional strategies, and curriculum saliency. These components were defined and used to analyse the data collected in this study, which specifically examines TSPCK in the context of teaching biotechnology.

According to Rollnick, & Mavhunga (2016), measuring the knowledge teachers gain through experience can be challenging due to its subjective

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Article DOI: https://doi.org/10.37284/eajes.8.1.2604

nature. However, experienced teachers who effectively apply pedagogical content knowledge (PCK) share certain identifiable characteristics. Unlike broader professional knowledge, TSPCK focuses on teaching specific topics, such as biotechnology, rather than general disciplinary knowledge (Shulman, 1986, 1987). TSPCK reflects the nuanced understanding required to teach a particular topic, making it distinct from general pedagogical content knowledge (Rollnick, & Mavhunga, 2016).

TSPCK serves as the foundation for teaching subject-specific content like biotechnology. The "knowledge of content representation" refers to the ability to use specific tools—such as diagrams or demonstrations—to effectively convey content. "Knowledge of student understanding" involves recognizing students' prior knowledge and identifying areas where they may struggle with certain concepts. "Knowledge of instructional strategies" refers to the ability to select and apply effective teaching strategies tailored to the subject matter and student needs. Finally, "science practices" encompass the ability to engage students in scientific exploration, including data collection, analysis, and interpretation during classroom activities.

The interaction between personal PCK and the classroom context takes place during classroom instruction (Gess-Newsome, 2015). In this study, personal PCK is defined as the teacher’s knowledge of reasoning skills, planning, and teaching a specific topic like biotechnology, ensuring that students grasp all key concepts. Classroom practice involves two main components: enactment and classroom context. Enactment refers to how a teacher's professional knowledge (TPKB) and TSPCK are translated into instructional practices in the classroom, where teachers use various teaching tools like charts, models, and scientific apparatus. This study specifically examined the components of TSPCK demonstrated in classroom practice (Figure 1).

Topic-Specific Pedagogical Content Knowledge (TSPCK)

Possessing content knowledge or pedagogical knowledge alone does not equate to having Pedagogical Content Knowledge (PCK). PCK, as highlighted by Smith, & Banilower (2015), is more than the sum of these two components, as it integrates other knowledge bases to create a unique teaching skill set. Content knowledge, however, remains central to PCK because it is always subject-specific—whether biology or a specific topic within it, like biotechnology, or even a particular concept within that topic, such as genetic engineering (Hashweh, 2005).

Rollnick, & Mavhunga (2016) emphasize the importance of considering specific components of PCK when teaching particular topics. These components—students' prior knowledge, curriculum saliency, content representations (e.g., powerful examples and analogies), and conceptual teaching strategies—are key to effective teaching. These elements align closely with those of the Teacher-Specific Pedagogical Content Knowledge outlined in the Consensus Model (Gess-Newsome, 2015).

Instructional (Teaching) Strategies

Instructional strategies refer to the teaching methods that are most effective for delivering a specific topic. In this study, they focus on strategies for teaching biotechnology, as outlined in the Malawi secondary school biology curriculum. Effective instruction involves various interactions: between the teacher and student, student and content, student and peers, and both the teacher and student with the environment.

A teacher's success hinges on their ability to manage these interactions and select appropriate strategies tailored to the complexity of the topic and the students’ knowledge level. The Malawi secondary school curriculum strongly recommends participatory, learner-centred teaching methods, such as group work, demonstrations, assessments, and exercises (MoEST, 2013). These strategies are further supported by a variety of teaching resources, including ICT tools, textbooks, and the local environment, to enhance practical, meaningful learning experiences.

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Content Representations

Content representations are the tools such as diagrams, photographs, simulations, and other resources that help explain a specific topic. These representations are vital in shaping how teachers convey knowledge and are a core component of TSPCK (Gess-Newsome, 2015). The use of content representations requires teachers to link students' prior knowledge, experiences, and misconceptions to the topic at hand. For instance, when teaching genetic engineering, a teacher might use pictures or simulations to visually represent the process, making the concept more accessible to students. However, the same phrase content representation, is also used as a technical term briefly written as CoRe. This is a form of methodology used to assess teachers' PCK and it is described under the data generation procedures and tools section.

Knowledge of Students' Prior Knowledge

Understanding students' prior knowledge and common areas of difficulty is essential for effective teaching (Magnusson et al., 1999). Loughranet al. (2012) developed an instrument called Content Representation (CoRe) to assess teachers' PCK. The CoRe consists of eight prompts, many of which overlap with Shulman's knowledge bases. These include understanding what students need to learn, why it's important, and what challenges students might face. One prompt specifically focuses on students' prior knowledge, which aligns closely with the concept of prior knowledge in the TSPCK consensus model (Rollnick, & Mavhunga, 2016). In their study, they compared the performance of two chemistry teachers in the teaching of organic chemistry topics. The aim was to identify and measure the level of different components of TSPCK at grade 12 level. The results showed that there was a differential performance in the different components of the TSPCK with the finding that the teachers showed an unexpected ability to select and sequence big ideas for teaching.

Effective teachers build lessons around what students already know and incorporate cross-cutting concepts and misconceptions into their teaching plans. In the context of biotechnology, teachers should draw on students' existing knowledge of related topics, such as genetics, to enhance their understanding of more complex concepts.

Knowledge of Curricular Saliency

Curriculum saliency refers to a teacher's ability to decide what content to teach, how to prioritize it, and the sequence in which it should be presented (Rollnick, & Mavhunga, 2016). This process involves making informed decisions about what is most important for students to learn, what should be emphasized, and what content can be postponed or omitted. Mavhunga, & Rollnick (2016) link curriculum saliency with several of the CoRe prompts, such as understanding what students need to know and why it is important for their everyday lives.

This knowledge enables teachers to make thoughtful decisions about the depth of coverage for certain topics, ensuring that key concepts are not only covered but also understood in a meaningful way. For instance, in biotechnology, a teacher may choose to focus more on concepts that directly relate to students' lives, like genetic modification, while delaying more abstract ideas for later lessons.

RESEARCH DESIGN AND METHODOLOGY

This study adopted an interpretivist paradigm to explore teachers' experiences in teaching biotechnology concepts. The interpretivist approach is particularly useful in understanding and interpreting the meanings teachers attach to their teaching experiences (Kivunja, & Kuyini, 2017). As Creswell (2012) notes, understanding the social context in which individuals live is essential, and the interpretivist paradigm allows the researcher to capture the participants' perspectives without imposing the researcher's own viewpoint. Interpretation, a key aspect of all qualitative research, was central to this study (Jackson et al., 2007).

A qualitative research approach was chosen because the data collected were textual rather than numerical. Qualitative methods are commonly used in studies related to knowledge bases such as content knowledge, TSPCK, PCK, and pedagogical knowledge (Mthethwa et al., 2015; Mphathiwa, 2015).

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Article DOI: https://doi.org/10.37284/eajes.8.1.2604

The study utilized a case study design, which is often employed in qualitative education research due to its flexibility, relevance to pedagogy, and transparency for readers (Creswell, 2012). Case studies provide an in-depth exploration of single or small groups of entities, such as individuals, schools, or communities (Polit, & Beck, 2008). In this study, the case study approach was suitable for investigating teachers' topic-specific PCK in teaching biotechnology. Data were generated through interactions with individual teachers in their schools using multiple data collection instruments.

A multiple case study design was used, allowing for an in-depth understanding of each case. Each teacher in the study was treated as a separate case, with individual analysis conducted before triangulating the data. As Creswell (2012) explains, case studies involve detailed, in-depth data collection over time from multiple sources to explore real-life cases.

Participants

Three experienced secondary school biology teachers—Joseph, John, and James (pseudonyms) were selected from a pool of teachers in the Central West Education Division, the study's focus area.

Joseph had been teaching biology for 15 years and held a bachelor's degree in education with a major in biology and chemistry. John had 17 years of teaching experience in biology and mathematics and held a diploma in education. James had 12 years of experience teaching biology and held a Malawi School Certificate of Education (MSCE) and a primary school teaching certificate. Table 1 summarises the participants' teaching experience, qualifications, subjects taught during the study, and the types of schools they were teaching in. The case study covered the teachers who were actually in practice because they formed a rich source of data. Therefore, these teachers were purposely selected firstly, based on their experience and that they would have been teaching a form 4 class with at least five years of teaching experience by the time the research study would be commencing. Purposive sampling was used because it targets participants with more knowledge of the subject at hand, therefore, allowing the collection of rich information to understand the case in its totality as they met the criteria and it is less expensive (Kumar, 2014). Similar studies have had either two or four participants as the maximum number used (Mthethwa-Kunene et al., 2015; Bravo, & Cafre, 2016).

Before any data collection, permission was sought from all relevant authorities. These included the University of Malawi through the Department of Mathematics and Science Education which is under the School of Education, Ministry of Education and the heads of the institutions where both the piloting and the main study were conducted. Participants were informed about the purpose of the study. Furthermore, all participants' names and details were kept anonymous from the public. Any information collected in the research was used only for the sole purpose of this research and for academic purposes. And no third parties had any access to private and confidential information as well as the data collected. Participants' consent to participate and freedom to withdraw from the study at any time as they wish was observed.

Table 1: Participants' Profiles Involved in the Study

Participant	Teaching experience	Qualification	School type	Subjects majored to teach	Subjects currently teaching
Joseph	15 years	Bachelor of Education	CDSS **X**	Biology and Chemistry	Biology and Chemistry
John	17 years	Diploma in Education	CDSS **Y**	Mathematics and Biology	Biology and Agriculture
James	12 years	MSCE	CDSS **Z**	None	Biology

Data Generation Procedures and Tools

To develop a comprehensive understanding of each teacher's topic-specific pedagogical content knowledge (TSPCK), including content representation, knowledge of students' prior knowledge, and curriculum saliency, data were collected using four different methods: Content

Article DOI: https://doi.org/10.37284/eajes.8.1.2604

Representation (CoRe), interviews, classroom observations, and document analysis. Each tool was designed to address one or more research questions by targeting the areas of planning, teaching, and reflection, thereby investigating the components of the biology teachers' specific pedagogical content knowledge for teaching biotechnology. As Wilson et al. (2018) explain, PCK is a form of professional knowledge visible in teachers' work, encompassing planning, teaching, and reflecting.

Content Representation (CoRe), developed by Loughran et al. (2012), was used to assess teachers' PCK. CoRes provides a broad overview of how teachers approach teaching an entire topic, including the rationale behind their methods (Mulhall et al., 2003). CoRe templates show what content is taught, how it is taught, and why, offering insight into the teacher's approach to delivering the topic. Mim et al. (2017) argued that using CoRe templates allows researchers to understand how teachers conceptualize specific subject matter. CoRes offers a "generalizable form of the participating teachers' pedagogical content knowledge, linking the how, why, and what of content to what they consider important in shaping students' learning and teachers' teaching" (Loughran et al., 2012, p. 17).

Interviews were another key data collection method. Matthews, & Ross (2010) describe interviews as a technique that allows researchers to elicit facts, feelings, and opinions through questions and interaction. In this study, semi-structured interviews were conducted to explore teachers' knowledge, with follow-up questions for clarification or elaboration. Interviews are a crucial source of qualitative data, providing insights into aspects of teaching that cannot be directly observed (Willig, 2013). They were used to explore teachers' perspectives on their teaching methods and how they assess student learning during and after lessons. Semi-structured interviews were selected for their flexibility, as they allow interviewers to use a prepared guide while adapting the order of questions based on the interviewee's responses (Bailey, 2007). Interviews were conducted before and after the classroom observations.

Classroom observations were also conducted to gather data on teachers' content knowledge, instructional strategies, pedagogical applications, and other knowledge bases, including TSPCK components. According to Creswell (2014), classroom observation allows researchers to immerse themselves in the research setting and gain firsthand insight into social actions, behaviours, interactions, and relationships. Three lessons were observed and video-recorded for each teacher to reach saturation. The observation data were then transcribed and analysed to investigate the components of TSPCK. This method provided rich qualitative data, helping the researcher visualize what transpired during the biotechnology lessons (Aydemir, 2014).

Document analysis served as an additional source of data. Creswell (2012) distinguishes between primary documents, authored by the participants (such as lesson plans and notes), and **s**econdary documents, authored by others but used as reference materials (such as textbooks). In this study, documents such as senior secondary biology syllabi, recommended biology textbooks, participants' lesson plans, and CoRe templates were examined. These documents helped reveal the teachers' understanding of biotechnology and their pedagogical choices. Through document analysis, the researcher gained insights into current teaching practices and issues related to the topic of biotechnology.

STUDY FINDINGS

The study aimed to identify the components of biology teachers' topic-specific pedagogical content knowledge (TSPCK) demonstrated in their CoRes and classroom practices. TSPCK involves transforming subject matter into teachable content and encompasses components such as Knowledge of Instructional Strategies, Content Representations, Curricular Saliency, and Students' Understanding of Teaching Difficulties. Data from the teachers' CoRes, interviews, and lesson observations were analysed to evaluate these components.

Given the complexity of deriving "Big Ideas" for a topic like biotechnology, the researcher collaborated with biology lecturers and an expert in CoRe development. The adapted biotechnology CoRe, originally developed by Garritz, & Velazquez (2009) for the Chilean curriculum, was slightly modified to

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Article DOI: https://doi.org/10.37284/eajes.8.1.2604

fit the Malawian curriculum. The Big Ideas developed with the experts included:

- **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 in drugs and food production
- **Big Idea E**: Ethical implications of biotechnology

The three participating teachers developed CoRes based on this template, which was refined using feedback from interviews and lesson plans.

Findings on Joseph's TSPCK

Joseph demonstrated awareness of various teaching strategies for biotechnology, including questioning techniques, discussions, demonstrations, and brainstorming. However, his CoRe lacked justification for his chosen strategies and details on how each would be applied in the classroom. Joseph outlined content for all Big Ideas but in a summarised form, with little explanation. He provided general success criteria but did not offer strong justifications for teaching the Big Ideas or a clear description of the content.

Joseph did not describe any visual aids or instructional tools, such as illustrations or charts, to help students grasp abstract concepts in biotechnology. Joseph identified four challenging areas in biotechnology for students, including selective breeding and the abstract nature of biotechnology concepts. He also noted the difficulty in conveying the long-term implications of biotechnology since the results are not immediately observable.

Joseph anticipated misconceptions about yeast's role in biotechnology and speciation in relation to plant and animal breeding. However, he provided limited details about students' misconceptions of other biotechnology concepts.

Findings on James' TSPCK

James' performance was strong across three TSPCK components—Knowledge of Teaching Strategies, Curricular Saliency, and Content Representation but weaker on the remaining components.

James provided clear explanations for his teaching strategies, including using "think, pair, and share" to encourage independent thinking, and discussions to engage students. He also mentioned using explanations for complex topics like genetic engineering.

James detailed the content under each Big Idea, such as biotechnology's impact on various disciplines and everyday life. He also outlined objectives, like fostering students' scientific curiosity and creativity, and explained how these would help students apply scientific and indigenous knowledge to solve problems.

James enriched his CoRe with explanatory notes and examples. He also identified the teaching procedures and materials, such as textbooks and charts, that he would use during lessons. James highlighted the challenges posed by the lack of teaching materials and his own limitations in handling certain experiments, which he found in non-curriculum reference materials. He criticised the curriculum for lacking hands-on activities such as extraction of DNA, which made biotechnology teaching theoretical and abstract. James noted that students did not recognize local practices like brewing beer and bread-making as biotechnology applications.

Overall, James' TSPCK was the most developed among the participants, especially in terms of instructional strategies, curricular saliency, and content representation.

Findings on John's TSPCK

John showed a good understanding of Students' Prior Knowledge and Misconceptions, but struggled with Content Representation and identifying what is easy or difficult for students. He also struggled to articulate his Instructional Strategies.

John mentioned debates and experiments as his primary strategies for teaching biotechnology, with debates being used for ethical discussions and

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experiments for abstract concepts. However, the biotechnology curriculum did not recommend experiments, and John could not explain how he would use them in practice.

He provided content for all five Big Ideas, but his explanations lacked clarity, especially under Big Idea C (genetic engineering). He failed to describe the process of genetic engineering and did not provide justifications for teaching it. His sequencing of concepts within the Big Ideas was often inaccurate, and he included information not covered by the curriculum.

John simply outlined the content without providing reasons for teaching it or suggesting how to make abstract concepts accessible to students. He did not identify activities or illustrations to assist in teaching. He believed that his students would easily understand concepts like artificial selection, due to prior knowledge from Form 3 Agriculture. However, observations showed that students struggled with these concepts. He identified several misconceptions, such as the belief that DNA is found only in animals, not plants. Although he noted these misconceptions, he failed to provide a rationale or basis for them.

In summary, John's TSPCK was evaluated as "developing." He struggled to provide detailed explanations for the Big Ideas and often presented content in a disorganised manner. His limited attendance at Biology SMASSE INSET sessions and lack of proper planning may have contributed to his weaker pedagogical skills in teaching biotechnology concepts.

DISCUSSION OF THE FINDINGS

Topic-specific pedagogical content knowledge (TSPCK) is the foundation through which knowledge of a subject is transformed into teachable content (O'Brien, 2017). TSPCK comprises various components such as teaching strategies, content representation, curricular saliency, and knowledge of students' prior knowledge. The findings related to each TSPCK component in this study are discussed below.

Topic-Specific Teaching Strategies Used in Biotechnology

Rollnick, & Mavhunga (2016) define teaching strategies as methods and procedures used to assess students' understanding or confusion about a concept. In this study, teaching strategies encompassed the methods and approaches teachers employed to help students grasp the material. The recommended textbooks, including Avis et al. (2018) and Njolinjo (2014), suggested topic-specific strategies such as fieldwork and individual exercises. However, teachers reported not implementing these strategies due to time constraints.

Pre-lesson interviews revealed that participant teachers were aware of both subject-specific and topic-specific teaching strategies. Despite this, classroom observations showed that all teachers heavily relied on the lecture method, even though none had indicated they would use it in interviews or in their CoRe (Content Representations). During post-lesson interviews, the teachers explained their difficulty in varying teaching methods, citing limited time and pressure to prepare students for national examinations as barriers to using more student-centred strategies. This was also observed by Knippels et al. (2005), whose research highlighted the influence of examination pressures on the amount and quality of content taught.

All teachers mentioned common teaching strategies like question-and-answer, group work, and pair work. However, some teaching strategies were unique to specific teachers. For example, James used peer teaching and observation, while John mentioned discussion and demonstration, although he rarely used them in practice. Both Joseph and John extensively used the lecture method, even though they did not mention it as part of their planned strategies.

These findings suggest that while the teachers were aware of participatory teaching strategies, they struggled to implement them effectively. Participatory learning, or cooperative learning, is widely regarded as the most effective approach to teaching biotechnology (Hin et al., 2019). Cooperative learning encourages students to

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collaborate in small groups on tasks (Wahab, 2020), and pre-lesson interviews indicated that the teachers were aware of its benefits.

An analysis of the Senior Secondary School biology syllabus revealed that it prescribes a uniform set of teaching strategies for all topics, including biotechnology. These strategies, such as question-and-answer, group work, and peer teaching, are intended to be adaptable, but teachers are expected to customise them for specific challenges in understanding biotechnology concepts. Despite this flexibility, teachers often did not employ the topic-specific strategies outlined in the textbooks, preferring more general methods due to time constraints. The absence of visual aids in the textbooks posed an additional challenge to effective teaching and learning. Teachers are unable to develop innovative teaching approaches that could have an impact on the students’ understanding of biotechnology concepts (Naz, & Murad, 2017).

Teachers’ Knowledge of Students’ Prior Knowledge

According to the adapted consensus model, understanding students’ prior knowledge is essential both as part of a teacher’s professional knowledge base and as topic-specific pedagogical content knowledge (PCK). Recognizing students' prior knowledge including misconceptions and learning difficulties is vital for effective teaching, particularly in complex subjects like biotechnology.

This component of teaching focuses on integrating crosscutting concepts into a topic and identifying students' pre-existing knowledge or misconceptions. It is a key element of TSPCK (topic-specific pedagogical content knowledge) and was notably developed among the three participants, as reflected in their CoRes (Content Representations). Each teacher had a general understanding of their students' existing knowledge and anticipated misconceptions.

During interviews, the teachers expected their students to have prior knowledge of key genetics concepts such as genes, DNA, and chromosomes, as well as an understanding of mitosis and meiosis from earlier lessons on reproduction. John further noted that his students had previously learned about plant and animal breeding in reproduction topic he taught in the previous year when they were in Form Three. Joseph identified specific misconceptions, such as students not understanding the role of yeast in biotechnology and confusing plant and animal breeding with speciation, a topic covered just before biotechnology under the core element of Genetics and Evolution.

Despite being aware of these misconceptions, both Joseph and John did little to assess their students' prior knowledge systematically. It was anticipated that they would use initial lessons to identify gaps, areas of difficulty, or misunderstandings, but they did not do so consistently.

All three teachers demonstrated awareness of their students' foundational knowledge and potential misconceptions. However, this awareness did not always translate into effective teaching strategies. For instance, although Joseph and John were aware of their students' misconceptions, they did not adjust their teaching methods to address these difficulties. James, on the other hand, used concrete examples, such as scissors and paper, to help students visualize abstract concepts like the formation of recombinant DNA. This hands-on approach helped his students better understand complex ideas. In contrast, Joseph and John did not use similar concrete representations, which may have hindered their students' understanding of more abstract biotechnology concepts.

Joseph recognised specific misconceptions, such as confusion between speciation and biotechnology, but did not effectively address these in his teaching. For example, he did not clearly differentiate between speciation (covered in the Evolution topic) and plant and animal breeding within biotechnology, leading to ongoing misunderstandings. Joseph’s inability to address these misconceptions, despite his awareness of them, reveals a lack of preparedness in teaching these concepts. His failure to connect plant and animal breeding with biotechnology, rather than speciation, highlights a gap in his instructional strategy and readiness.

Data also indicated that James was aware of his students' prior knowledge regarding various biotechnology concepts. He took this into account during his planning and preparation, developing

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Article DOI: https://doi.org/10.37284/eajes.8.1.2604

illustrations and activities to teach biotechnology more effectively such as what he had taught the students in genetics (Van Driel et al., 2014). James also provided more detail on how he planned to address the diverse needs of his students than Joseph and John. This demonstrated that James was more sensitive to the context and needs of his learners. He drew on his knowledge of the applications of biotechnology at the household level, enabling students to connect familiar concepts with more abstract ones.

John, however, showed limited knowledge of his students' prior understanding and misconceptions. The prior knowledge he referenced during pre-lesson interviews did not match what emerged during the actual lesson. He assumed his students would easily grasp animal and plant breeding since they had learned about it in Form Three agriculture. However, after teaching the topic, his students struggled to explain hybridisation. In the post-lesson interview, John attributed their failure to recall past learning rather than a gap in his instruction. In his CoRe, John also identified misconceptions he expected students to have regarding biotechnology, suggesting that he did know his students well. Teachers' knowledge of their students is crucial, as highlighted by Lucero et al. (2019), who argue that allowing teachers to describe their students' thinking provides deeper insight into their learning.

All three teachers predicted which areas of biotechnology would be difficult for their students. Joseph specifically noted genetic engineering as a challenging topic due to its abstract nature, which is difficult to observe in real life. James, on the other hand, pointed out that the lack of hands-on experiments in biotechnology was a significant barrier to student understanding.

The researcher's assessment of these anticipated difficulties suggests that the teachers lacked innovation and critical reflection on how to simplify abstract concepts and make them accessible to students. Although the teachers demonstrated awareness of the prerequisite knowledge needed to understand biotechnology, they lacked creativity in their teaching approaches, ultimately reflecting a deficiency in their PCK.

Teachers' Knowledge of Curricular Saliency

According to Rollnick, & Mavhunga (2016), curricular saliency involves determining what is essential for teaching, how to sequence concepts within a topic, and what to introduce first versus postponing. All the teachers in this study aligned the content with the appropriate Big Ideas in their CoRes. However, they struggled to provide a rationale for the sequence of subtopics they chose. During instruction, the teachers typically followed the sequence outlined in the syllabus or textbooks. Most textbooks adhere to the syllabus, but John missed important content by relying on a single textbook that did not cover all the required material.

The researcher observed that Joseph and John over-relied on textbooks for planning and teaching their biotechnology lessons. James, however, varied his resources, using approved textbooks, the syllabus, and additional materials from an in-service training he attended. His lesson plans were detailed, clearly outlining what and how he planned to teach. During lesson observations, it was noted that James followed his lesson plan thoroughly. Joseph, in contrast, used only one approved textbook and the syllabus, claiming he had identified errors in other textbooks. However, the researcher found no significant errors in how other sources presented biotechnology concepts.

Relying on a single textbook can lead to shallow content and erroneous success criteria. For example, John, who used only one textbook to plan his lessons, devised his own success criterion, which was incorrect. Rather than using the correct success criterion "Students must be able to describe the process of genetic engineering" he stated, "How new genes are formed by modifying DNA of an organism to produce new genes with new characteristics." Using only one textbook also led to vague explanations, unclear content, and difficulty answering students' questions.

During lesson observations, it became evident that teachers who did not prepare comprehensive lesson plans and who used limited resources struggled. For instance, when asked by a student, "How are genes transferred in plants?" John responded, "They are

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injected just like with an injection," showing that he was not equipped to explain the concept adequately.

John and Joseph primarily used declarative knowledge to describe biotechnology concepts, extracting definitions straight from their textbooks. James, however, used both declarative and procedural knowledge, adapting content from multiple sources. He did not use conditional content knowledge, as his questions were not high-order. However, his varied teaching strategies helped keep students engaged throughout the lesson. Teachers must periodically assess their students' declarative or content knowledge, procedural knowledge, and conditional knowledge. Declarative knowledge is the knowledge of facts and relationships (Yilmaz, & Yalcin, 2012). Procedural knowledge refers to the procedures, processes, and skills required to perform a task or activity. This requires executing steps in a particular sequence to achieve a desired outcome or goal. Conditional knowledge is knowing when and why to use declarative and procedural knowledge (Yilmaz, & Yalcin, 2012). According to Yilmaz, & Yalcin (2012), conditional knowledge requires critical thinking and problem-solving strategies to use conditional knowledge very well.

James used multiple textbooks in class, distributing them among five groups of students. Due to the limited number of textbooks, individual reading assignments were not feasible. John and Joseph's schools also had textbooks available, but the teachers did not include them in their lesson plans or bring additional copies to class.

Topic-Specific Strategies in Practice

Joseph used a hands-on approach, such as showing students different maize hybrid seeds, which helped them visualize and engage with biotechnology concepts. Both Joseph and James used illustrations and diagrams to explain abstract concepts, aiding student understanding. In contrast, John's approach lacked practical examples, and he began lessons without assessing students' prior knowledge, limiting their engagement.

Group work was another strategy employed by all three teachers. Students were organized into mixed-ability groups, typically consisting of eight students, with the aim of peer support. Joseph and John also incorporated pair work at the beginning of lessons to facilitate brainstorming before transitioning to group activities. James, however, added a unique element by providing different textbooks to each group and asking them to read, discuss, and summarize the content. This approach promoted active engagement and collaboration among students.

While lectures were widely used by all teachers, their effectiveness varied. Joseph's lecture on genetic engineering, for example, lacked illustrations, leading to incomplete understanding among students. In contrast, James supplemented his lectures with group work and visual aids, which helped reinforce students' understanding of genetic engineering.

Adherence to Curriculum and Time Constraints

Despite following the same content sequence for topics like plant and animal breeding, the depth of content delivery varied among teachers. John went beyond the MSCE curriculum, covering content that was not part of the syllabus, while James and Joseph adhered more closely to the prescribed content. This highlights the importance of aligning teaching with curriculum guidelines to ensure consistency in the depth of content coverage.

The biology curriculum and textbooks did not include practical work as part of the recommended teaching strategies for biotechnology. This omission reflects the complexity of the subject matter at the MSCE level, which has led to a reliance on theoretical approaches. Teachers, therefore, were limited in their ability to incorporate hands-on learning experiences into their lessons.

None of the teachers mentioned or used ICT tools, despite the syllabus recommending their use. This might be due to a lack of familiarity with ICT or the absence of necessary equipment. Studies have shown that ICT tools, such as virtual experiments and animations, can enhance students' understanding of abstract biotechnology concepts (Bonde et al., 2014; Orhan, & Sahin, 2018). These tools could potentially compensate for the absence of physical experiments by providing interactive and visual representations of complex processes.

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Missed Opportunities in Teaching Strategies

Despite the effectiveness of modelling as a teaching strategy (Salisu, & Ransom, 2014; Hin et al., 2019), none of the teachers employed this approach. Modelling, which involves demonstrating new concepts through observation, helps students understand abstract ideas by visualizing them in practice. Its absence in the teaching of biotechnology represents a missed opportunity to deepen students' comprehension of the subject.

The lecture method, though predominant, was less effective without the use of visual aids or interactive components. Teachers cited time constraints and the pressure of covering extensive content before national examinations as reasons for relying heavily on lectures. This transmission model of teaching, where knowledge is primarily delivered by the teacher, limits student engagement and discourages deeper learning (Aydemir, 2014). Although teachers expressed a desire to use more student-centred strategies, factors like exam pressures, lack of resources, and time constraints hindered their ability to do so effectively.

The reliance on lectures, coupled with the absence of teaching aids, led to monotonous lessons and reduced student engagement. A review of currently recommended textbooks revealed that they lacked topic-specific teaching strategies or activities that could enhance students' understanding of biotechnology. Additionally, despite the curriculum's suggestion to use ICT, none of the textbooks included strategies leveraging this tool to improve comprehension of abstract concepts. This reflects a gap between teaching resources and modern educational practices.

In conclusion, while teachers were aware of various topic-specific and general teaching strategies, the pressure of national exams, lack of resources, and rigid curriculum guidelines limited their ability to fully implement student-centred and participatory learning approaches. This ultimately impacted the depth of student understanding and engagement in biotechnology lessons.

Content Representations

Gess-Newsome (2015) defines content representations as diverse methods employed to illustrate a topic, including photographs, diagrams, simulations, tables, and both oral and written presentations. In this study, the component of content representations was not fully incorporated to demonstrate the transformation process in the participants' CoRes (Content Representations). While Avis et al. (2018) and Njolinjo (2014) offered various representations and activities that could enhance understanding, Joseph and John did not utilize these resources. In contrast, James effectively incorporated a diagram from Avis et al. (2018) illustrating the process of genetic engineering, transferring it onto a large chart for his lessons.

Miheso, & Mavhunga (2020) assert that teachers with strong content knowledge are better equipped to use illustrations and drawings effectively in their teaching. Although Joseph employed some rudimentary sketches, John did not incorporate any illustrations or visual aids. This suggests that both Joseph and John lacked the knowledge and skills necessary to effectively present the genetic engineering process to their students.

CONCLUSION

The analysis of the components of topic-specific pedagogical content knowledge (TSPCK) revealed that not all teachers effectively demonstrated all four components. Some teaching strategies used, such as the lecture method, were not mentioned in the interviews. All participants employed subject-specific teaching strategies, including group work and question-and-answer techniques. However, James excelled in creating clear representations, illustrations, and diagrams, significantly enhancing his ability to explain genetic engineering. In contrast, Joseph's sketchy diagram failed to convey the concept effectively to students, and John, despite being aware of his students' understanding and learning difficulties, did not address these issues effectively in class. For instance, although John identified the common misconception that "only animals have DNA while plants do not," he struggled to provide a clear explanation when a student inquired about it. Similarly, Joseph and

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James were unable to leverage their knowledge of challenging areas to facilitate better understanding, particularly regarding the genetic engineering process.

The teachers predominantly adhered to the syllabus and textbooks for guidance on content and sequencing. However, John's reliance on a single textbook led him to overlook crucial success criteria outlined in the syllabus, resulting in an inability to meet curriculum objectives.

Moreover, the teachers did not demonstrate several components of topic-specific pedagogical content knowledge as described in the literature, including 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.

The study recommends that curriculum developers ensure textbooks contain comprehensive content, including clear illustrations and activities aligned with the syllabus, to better support teachers and students in understanding and applying biotechnology concepts effectively as they are abstract.

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