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An exploration of first-year medical students' prior knowledge of cell biology and the potential effectiveness of technology integration in bridging the gaps.

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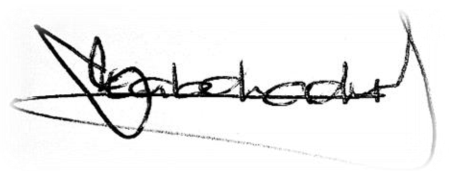
Finally, I would like to thank God for His grace during the course of the entire dissertation.

DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the fulfilment of the degree of Master of Science (Dissertation) at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other university, nor has it been prepared under the guidance or with the assistance of any other body or organization or persons outside the University of the Witwatersrand, Johannesburg.



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ABSTRACT

First-year medical students' prior knowledge of cell biology could provide insight into their subsequent understanding. This research project was conducted to explore first-year medical students' prior knowledge of cell biology and the potential effectiveness of technology integration in bridging the gaps. To address this aim, I determined whether there were gaps in first-year medical students' knowledge of cell biology and how students and lecturers addressed any gaps with the use of technology. The study was conducted with students and their lecturers at a university in Gauteng, South Africa over 2020 and 2021. Data was collected through interviews with staff, questionnaires with students, by analysing assessment responses on content related to cell biology, and analysis of online lessons given to students. From the data collected, it was found that the majority of students do not have a holistic understanding of cell biology from high school. Consequently, students may be unable to accommodate successive knowledge taught in first-year. The study also revealed that first-year lecturers are vaguely aware of the content that is taught in school. Lecturers also indicated that the use of technology could enhance students understanding of cell biology concepts. This belief was confirmed to some extent, with the use of technology as part of the teaching practice. The results of this study indicate that the concept of the cytoskeleton, a component of the animal cell, may need to be introduced at high school level, as it is critical for the understanding of many intracellular processes. Secondly, lecturers may need to become more aware of what the high school syllabus offers so that their teaching is better aligned with the knowledge that students have when they enter their first year. They can then better scaffold the students' learning through the Zone of Proximal Development (ZPD) from their knowledge at high school to their understandings developed at university. In addition, technology has the potential to mitigate conceptual challenges by enabling students to visualize the dynamic and abstract characteristics of cells and may need to be used to teach this concept using the Technological, Pedagogical and Content Knowledge (TPACK) framework.

Key Words: Cell biology, Technology, Constructivism, Technological Pedagogical and Content Knowledge (TPACK).

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CHAPTER ONE

1.1. INTRODUCTION

In my Honours degree, I was asked to research and present the concept of the cytoskeleton to my colleagues as part of the assessment for the cell biology topic. The concept of the cytoskeleton was new to me, and I felt disadvantaged in not being exposed to the content when I was a learner in school. After I had acquainted myself with the content, I tried to determine how best to represent it. As a high school teacher, in my instruction of cell biology, I have found that learners have many preconceived ideas about the structure of the cell and that this is difficult to resolve using traditional, lecture-style instruction methods. This is because telling learners that a model is three-dimensional does not allow them to create the mental representation, as most instructional aids are two-dimensional textbook drawings (Vijapurkar, Kawalkar & Nambiar, 2014). I also realized that both two- and three-dimensional images would not be able to demonstrate the dynamic nature of the cytoskeleton. I then decided to use videos to aid my presentation of the concept to my colleagues. As my lecturer had told me that this was a successful method to teach this section, I decided to determine the extent to which the use of technology affects learners' understanding of abstract cell biology concepts at high school.

From my Honours research results, I found that if images do not reflect the true nature of cell components, misrepresentations may lead to misconceptions, which is an incorrect view based on flawed understanding (Lalbahadur, 2019). My findings had shown that with the use of technology, learners could visualize the three-dimensional nature of the cell. As part of my Honours research, I had also read about the extent to which the policy documents prescribed cell biology content at high school. According to my analysis of the Curriculum and Assessment Policy Statements (CAPS) document for the Further Education and Training (FET) phase (Grades 10-12) for Life Sciences (LS), I had found that the content under the cell biology concept is not covered in much depth (Department of Education (DoE), 2012a). This is a concern, as a firm foundation of this concept is essential for first-year medical students' understanding of cell biology, and especially histology. Bearing this in mind, I sought to determine how cell biology is built on in the first-year cell biology syllabus with the use of technology as this idea would likely support the students' capability to visualise the cell as a three-dimensional structure amongst its various other functions.

The definition for technology, as used in this study, includes videos, microscopes, computer simulations, virtual laboratories, and PowerPoint presentations. As there are various forms of technology, I wanted to look at the effective use of this technology in the instruction of cell biology content knowledge within a first-year class. This interplay between content knowledge, pedagogical knowledge and technological knowledge was examined using the Technological Pedagogical and Content Knowledge (TPACK) framework (Koeheler & Mishra, 2005). This framework implies that for instruction with technology to be effective, all three types of knowledge (i.e. knowledge on technology, pedagogic practice, and content) have to be present in the lecturer. In other words, TPACK can be a model in which to view the extent to which effective instruction can be achieved with the use of technology.

However, instruction may be inefficient if the student is unable to accommodate or assimilate the new knowledge into their current preconceptions, which are opinions formed in advance of true knowledge (Meheut, 2012). This relationship forms the basis of the theoretical framework known as constructivism, a learning theory largely credited to Jean Piaget. Piaget shows that intellectual growth is a process of adaptation through assimilation and accommodation (Piaget & Cook, 1952). Elkindir (2020) argues that this is best done through student-centred strategies, rather than lecturer-centred strategies. Student-centred strategies imply that students contribute to the growth of their knowledge, whereas lecturer-centred methods make content available to students in the form of notes which students have to recite and/or memorise (Elkindir, 2020). Lecturers may assist students through the ZPD, with the use of technology, as the More Knowledgeable Other (MKO), for students to gain epistemological access (Vygotsky & Cole, 1978). This is important as epistemological access affords students access to both theoretical and practical aspects of disciplinary knowledge (Muller, 2014).

There is limited research on technology use during instruction of cell biology amongst first-years studying biology at university. Therefore, this study could be useful in attempting to decipher the effect of the use of technology to teach this topic, as well as other biological concepts. This is a timely study. Due to the COVID-19 pandemic, South African universities have been forced to move their teaching to the online environment as they found it instrumental in student achievement and upholding access to education, and are likely to continue with a blended approach into the future (Mpungose, 2020a). Studies such as the present one, which investigates the use of technology, could inform changes in pedagogies and teaching practices that could be adopted as universities move to online teaching to strategically incorporate technology into teaching.

1.2. PROBLEM AND PURPOSE STATEMENT

Cells are referred to as the basic units of life because every living organism arises from cells (Campbell, Reece, Urry, Cain, Wasserman, Minorsky, and Jackson, 2015). Hasiloglu and Eminoglu (2017) state that in the study of cell biology many structures are difficult to visualize and that these structures become easier to see with the use of a microscope. This means that without the use of a microscope or similar technological device, cell biology may be difficult to understand because of the abstract nature of cells. Kapici and Savasci-Acikalin (2015), and Climer (2011), who state that this abstract nature is what may cause conceptual barriers, agree with this. In addition, concepts such as the cytoskeleton are not outlined in the CAPS syllabus taught in high school (DoE, 2012a). As such, learners may not engage with this concept before university and may not immediately grasp the dynamic nature of the cell. It is, therefore, important to explore first-year medical students' prior knowledge of cell biology and the potential effectiveness of technology integration in bridging the gaps.

1.3. AIM OF RESEARCH

To explore first-year medical students' prior knowledge of cell biology from high school and determine the potential effectiveness of technology integration in mitigating any possible gaps.

1.4. RESEARCH QUESTIONS

The following research questions formed the basis of the investigation:

1. What are the knowledge gaps between high school and first year university curricula, on the topic of cell biology?
    a. What evidence is there of curriculum continuity between high school and university?
    b. From the perspective of first-year lecturers and students, what preconceptions do students have on cell biology when they enter university?
    c. What connection exists amid students' preconceptions of cell biology and their understanding of important conceptions after instruction?
2. How do students and lecturers perceive the integration of technology in enhancing the students' understanding of cell biology?
    a. What are lecturers' current practices in the instruction of cell biology?
    b. What influence does exposure to learning using technology at school have on students' learning with technology at university?

CHAPTER TWO

2.1. LITERATURE REVIEW

Cell Biology Content Knowledge in High School

According to the CAPS document for Life Sciences (LS), the subject offers learners information and skills that are relevant for their daily lives (DoE, 2012a). This includes knowledge of their natural world, as well as providing them with analytical skills to evaluate societal aspects of science, such as vaccine use. Additionally, it exposes learners to natural phenomena to generate awareness of issues of interest, which may potentially lead to promoting studies and investigations in the field (DoE, 2012a). Kiboss, Ndirangu, and Wekesa (2004) also indicate that an understanding of biology is important for the benefit of individuals' livelihood and for preparing learners to develop in the science field after school.

In the CAPS document for LS, cell biology falls under a strand called 'Life at molecular, cellular, and tissue level' (DoE, 2012a, p.10). This strand is only explicit for Grades 10 and 12. However, sections in Grade 11, such as cellular respiration and photosynthesis, require basic cell biology knowledge too. In Grade 10, learners engage with the cell organelles and components individually and are exposed to foundational knowledge on cell division (DoE, 2012a). This is continued in the Grade 12 syllabus where learners go more in-depth into DNA, RNA, and the process of meiosis (DoE, 2012a).

Cell components that are covered in the CAPS syllabus include the nucleus, mitochondria, plastids, ribosomes, endoplasmic reticulum, Golgi apparatus, vacuoles, lysosomes, centrosomes, cytoplasm, and the cell membrane (DoE, 2012a). According to my analysis of the CAPS documentation, as well as my own experience as a Life Sciences (LS) educator, the nucleus is given the most attention for its functions in controlling the cell's activities and in cell division. The mitochondria and chloroplast are covered to explain their roles in cellular respiration and photosynthesis respectively. The cell membrane is discussed briefly in terms of its structure, function, and movement across the membrane. The cytoskeleton, however, is not outlined to be covered when learners engage in knowledge of the cytoplasm (DoE, 2012a). This is concerning as the capability of a eukaryotic cell to transport intracellular constituents is influenced by this structure. The other cell components are covered briefly concerning their structure and function. As these concepts are not taught in-depth when learners engage in learning about cell structure during high school, students' conceptions of cell components may be lacking, as discussed next.

Prior Knowledge

Learners have many preconceptions of cell-related knowledge (Hasiloglu & Eminoglu, 2017; Niebert, Riemeier & Gropengieber, 2013; Dikmenli, 2010; Vijapurkar, et al., 2014; Treagust & Duit, 2008). Some preconceptions may be based on students' everyday experiences of natural phenomena that may cause inaccurate knowledge of cellular processes. Niebert et al.'s (2013) study provided one example of this type of understanding where students thought that the growth of an organism would depend on the multiplication of cells and not the enlargement of them.

Some preconceptions of the cell may be detrimental as, according to Treagust and Duit (2008), preconceptions and philosophies about natural phenomena may be firmly held by learners. This poses a problem for educators as it demonstrates that learners are holding the idea that cells are two-dimensional. Additionally, it shows that it is also difficult to change their perception, as they are unable to visualize the cells in a three-dimensional way. Learners' view of cells as two-dimensional can be seen in describing cell shape as "flat", "rectangular", "circular" or "oval" (Vijapurkar et al., 2014, p.19). Other researchers, such as Hasiloglu & Eminoglu (2017) and Niebert et al. (2013), have found similar evidence in their studies.

As stated in research conducted by Niebert et al. (2013) with learners in Germany, and Vijapurkar et al. (2014) with primary school learners in India, learners can give definitions of terminology but are unable to demonstrate a deeper conceptual understanding of phenomena. When asked to draw human cells, learners drew cells inside the body. This showed that learners perceived cells to be in the body rather than make up the body. Responses such as 'the cells under our skin are soft', accompanying a drawing of cells under a layer of skin, which is not made up of cells itself, are indicative of this conception (Vijapurkar et al., 2014, p.19).

According to Vijapurkar et al. (2014), learners are also susceptible to saying that a plant cell is a rectangular shape and an animal cell is an irregular shape. This preconception of cell shape limits students' understanding of the structure of cells, which, in turn, may limit their ability to understand different cells in a multicellular organism (Vijapurkar et al., 2014). A conceptual barrier that may then arise for university students, because of misunderstandings of the three-dimensional nature of a cell, is the inability to understand the cell as both a structural and functional unit of an organism.

Conceptual Development

In a study conducted by Climer (2011), learners reported that there are many reasons for their lack of understanding, including not studying frequently and not paying attention in class. Many students also stated that due to the content-heavy nature of biology, they adopt a memorisation learning strategy to remember biological facts temporarily for an assessment and this was inefficient in getting them to understand the content (Climer, 2011). In other words, even though they lack conceptual understanding, students adopted other methods of test taking to produce results rather than developing their understanding of biology. Momsen, Long, Wyse, and Ebert-May (2010) agree on this point, stating that in introductory biology courses, students may get high marks for assessments because the course is based on memorization of facts and that assessment is based on lower levels of Bloom's taxonomy, which is a classification of educational objectives. These authors also state that rote memorization of facts is a limitation on students' conceptual understanding (Momsen et al., 2010). Sung, Swarat, and Lo (2020) who conducted a similar study and revealed non-conceptual approaches used by students to answer questions on genetics further agree upon this. They revealed that some students developed problem-solving approaches that are not constructed on understanding or application of biological conceptions but were rather created from perceived pattern recognition in assessment questions (Sung et al., 2020).

Kapici and Savasci-Acikalin (2015) and Climer (2011), however, point out that conceptual barriers may be due to the abstract nature of cell biology concepts, as they are not concrete concepts with physical existence visible to the learners' naked eye. Many cell structures are not visible when viewed with a light microscope, which is the main type of microscope used in many classrooms at school and undergraduate courses. For Kapici and Savasci-Acikalin (2015), pictures in science textbooks play an important part to contest some of these preconceptions. Therefore, representations may play a vital role to contest the abstract nature of cell biology where the concepts are difficult to see with the naked eye.

In other words, since learners are unable to see cells with their naked eye, introducing learners to images of these cells should make the concept more concrete for them. However, in the study conducted by Kapici and Savasci-Acikalin (2015), they found that most textbooks reveal large-scale, macroscopic representations or sub-microscopic representations of natural phenomena. This means that instead of representing an actual cell, learners may be given drawings or other representations that do not feature the cell in its entirety and complexity.

This shows that learners still need other forms of representations to understand cell biology concepts if school textbooks are not providing enough of a view into the abstract depth and complexity of these concepts. Dikmenli (2010) looked at the use of models to improve the learning of cell division in biology. These models were considered good representations to use as they engage the students in instruction rather than the lessons being largely educator-centred.

The use of multiple representations is important as it might enhance learning more effectively (Veselinovska, Gudeva & Djokie, 2011). This is supported by the comments of students surveyed in a study by Climer (2011), who reported that the reasons for challenges in achieving a conceptual understanding of biological concepts included the lack of educator pedagogy, the lack of educator content knowledge, and/or the time constraints of an overloaded curriculum (Climer, 2011). Lecturers could adopt a variety of instruction and learning strategies, including technology-mediated strategies, to deal with these challenges, enhance learning, and address misconceptions more effectively.

Technology Use

According to Climer (2011), learners perceive that the best way for them to remember content is through audio-visual aid. Livingstone (2012) agrees with this as he states that Information and Communication Technology (ICT) can develop the quality of instruction and that it can improve learners' results. These may even be in terms of videos or game simulations as there are abundant indications that there are worthwhile experiences to the knowledge development of learners through ICT (Wellington, 2005). In other words, in contrast to other learning strategies, when using ICT, instruction and learning that is more meaningful can take place.

Technology, as a resource to teach cell biology content knowledge, can be described as a representation under Shulman's (1986) Pedagogical and Content Knowledge (PCK) model. PCK, as defined by Shulman (1986, 1987), is an awareness that goes beyond content knowledge, as it is a domain of understanding in which one knows how to teach the content by transforming it in a way in which learners will best understand the subject matter. Shulman stressed the importance of four different knowledge types. These are content knowledge (the material to be communicated to students), pedagogical knowledge (an account of the practises, procedures, plans, processes, and approaches for teaching and learning that the lecturer takes in planning and instruction), pedagogical content knowledge (awareness of learner needs concerning the content), and curriculum knowledge (understanding of the syllabus).

Using technology to teach touches on another aspect under Shulman's (1987) model of pedagogical reasoning and action. This aspect is called transformation, which refers to how content knowledge is changed to become relatable to learners. Shulman's notion of PCK here can consist of appropriate uses of technology as a representation for conceptual development for learners (Shulman, 1986). This is important, as theory may not always do justice to the dynamic nature of cell biology. According to Dupré and Nicholson (2018), biology should be seen as a series of processes rather than at the final stages after each process. Authors such as Kiboss et al. (2004) agree with this, as they report that simulations show learners the dynamic nature of cells. This means that, unlike static images, when learners have access to videos, they are more likely to understand the complex activities within a cell rather than the instructor merely trying to explain it to them.

Stith (2004) suggests that cellular processes could be presented using animation or simulation because it allows students to understand the cell as a complex, dynamic concept, which they cannot visualise with basic imagery. Stith (2004) proves this point by using the example of movement through the cell membrane to explain how this process is rather difficult to explain with the use of static illustrations. Movement through the cell membrane is a difficult process to explain to students if they do not understand the dynamic nature of the cell membrane but is easier to explain if they can see this motion with a simulation or animation.

Kiboss et al. (2004) similarly agree with the use of animation and simulation to teach about the process of cell division. Although cell division is traditionally taught with the use of images, using animations or simulations may enhance understanding as students see the dynamic movement during this process. These ways may make it easier for students to gain conceptual understanding without perpetuating misconceptions, as they are better able to see the dynamic nature of cells and cell components.

Novak (2003) takes this further by stating that learners need to be able to interrelate concepts and that this would require a deeper understanding of concepts. If students do not attempt to link new knowledge to their prior knowledge, this may lead to misconceptions. As such, Novak (2003) demonstrates the use of technology in developing interactive concept maps with learners to show interrelationships of concepts. He also asserts that if used effectively, it can lead to better conceptual development.

Effective Instruction

Effective teaching methods are of utmost importance as Sailer, Murbock, and Fischer (2021) state that teachers may not yet have sufficient skills to make the most out of the digital technologies in schools. Livingstone (2012) further argues that educators only give attention to technical aspects in which they feel most confident. This is vital as Voogt et al. (2013) stress that educators' beliefs about technology affect the extent to which they integrate it into lesson design and instruction.

The findings by Veselinovska et al. (2011), Climer (2011), Novak (2003), and Usak (2009), align with the Technological and Pedagogical Content Knowledge (TPACK) framework (discussed later) (Koehler & Mishra, 2005). These authors show the importance of educator content knowledge, using representations effectively, and being intentional about pedagogical choices. Pierson (2001) stated that when technology is incorporated into pedagogy, there are different levels of implementation, from having the technological infrastructure but not using it during instruction, to a point in which educators use technology to solve educational problems successfully. In other words, there are different levels of technology integration from available but not used, to the effective use of technology. Again, the keyword here is effective, as Usak (2009) states that effective instruction with technology is not always the case as educators may revert to using lecture-type styles of instruction with the addition of technology.

Lecture-type instruction involves passive students concentrating on a one-way transference of information (Zeng, Chen, Li & Wang, 2020). Usak (2009) found that majority of prospective educators in his study were not cognitive about learners' difficulties of understanding certain topics, which also shows lower pedagogical content knowledge, and may reflect why they used technology in a lecture-style approach. In other words, even with the access, if an instructor does not have pedagogical knowledge, it may lead to ineffective instruction. Therefore, TPACK should not be seen as mere technology integration in instruction; according to Voogt et al. (2013), it is the basis of effective instruction with technology.

In Novak's (2003) look at interactive technological concept maps, he emphasizes that learners can raise questions and comment on answers given by other learners in the programme in his study. This kind of interaction in TPACK is significant as the linked concept mapping and software show technological content knowledge, but without the pedagogy of the educator to guide the inquiry, TPACK would be ineffective.

This kind of classroom interaction and discussion is also very important as in Mnguni's (2013) research looking into the curriculum ideology of South African biology education, it was identified that biology has a student-centred ideology in the CAPS curriculum. The CAPS curriculum in South Africa emphasizes the interplay between theoretical knowledge and practical skills (DoE, 2012a).

Practical work encourages learner-centeredness and interaction and, as the learners in Climer's (2011) study point out, educators may achieve more learner involvement and intrinsic motivation to learn if the classroom environment is made more interesting. Veselinovska et al.'s (2011) study supports these findings; they have stated in their research that learner-centred learning is important. Luksa, Radanovic, Garasic, and Sertic-Peric (2016) explain that the best way to get learners to overcome misconceptions for cell division is through constructivism, which is an approach that emphasizes the use of learner-centred classroom arrangements.

2.2. THEORETICAL FRAMEWORKS

One of the theoretical frameworks used in this study is the TPACK framework as introduced by Koeheler and Mishra (2005) (Figure 1). This framework suggests that to achieve effective instruction, lecturers would not only need to have an awareness of content, pedagogical and technological knowledge, but they would also have to understand the relationship between these three domains. The success of the incorporation of the domains of knowledge would be the distinction between building knowledge and enabling meaningful learning to take place. This is important as knowledge can be transferred to students but unless it is done so effectively, meaningful learning may not take place.

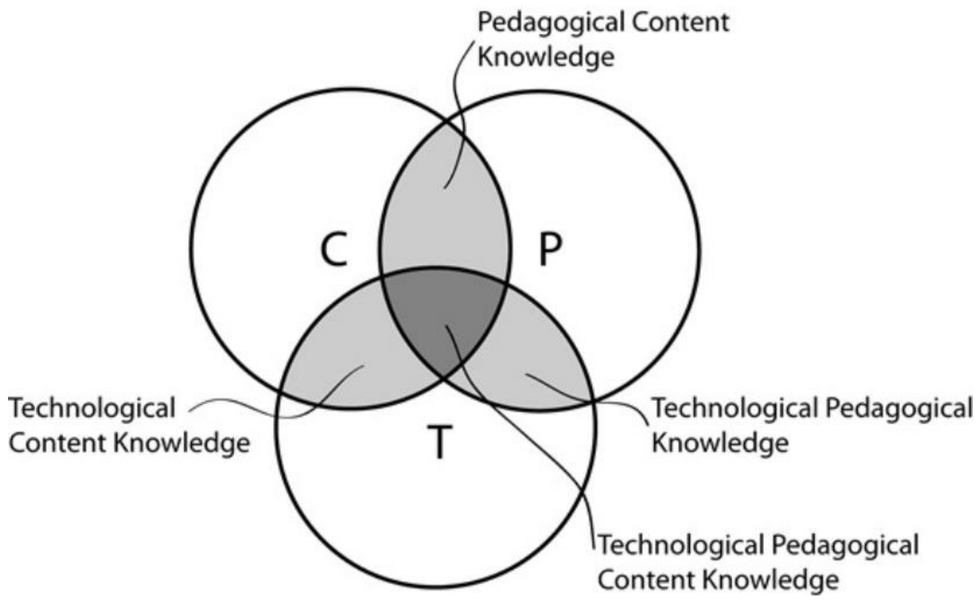

Figure 1: TPACK Framework (Koehler & Mishra, 2005)

The emphasis here is to illustrate and outline the independent domains of knowledge, but also to show their interdependence on one another in order to move in the direction of a more transactional and co-dependent structure that shows a thoughtfulness behind the different kinds of technology integration. Where the authors focus their framework on its significant implications for teacher education and teachers professional development, my aim is to use it as a theoretical framework in order to assess the effectiveness of technology use in teaching cell biology concepts.

For this reason, Kececi and Zengin (2017) found that training courses are necessary to develop TPACK environments. Kafyulilo, Fisser, and Voogt (2012) who conducted a their study of in-service educators in Tanzania, say that once educators were exposed to development in TPACK, there was an improvement in their technological pedagogical knowledge, which, in turn, had a positive impact on learners' interest in science. In other words, not only does instruction with the use of TPACK enhance the understanding of science, but it also has other benefits such as increasing interest in the field. In addition, they saw educators develop in their pedagogical content knowledge as they engaged better in the development of lessons and took into account the understanding of representations of ideas (Kafyulilo et al., 2012). Therefore, when educators became cognisant of the domains of knowledge, they produced lessons that were more effective for meaningful learning. Consequently, for Koehler, Mishra, Kereluik, Shin, and Graham (2014), the development of TPACK is a significant area of investigation due to its important inferences for educator professional development. This is why it can be a useful tool in determining effective instruction with the use of technology at university.

TPACK aims to assist in making instruction more learner-centred (Voogt et al., 2013). Learner-centred instruction views students as active contributors in their learning, with their learning formed by their interests, previous conceptual understandings, and active exploration of new knowledge. TPACK does this through the interplay of the various concepts. Valtonen, Kukkonen and Wulff (2006), found that, even though the affordances of technology could effortlessly support learner-centred methods, educators have a habit of choosing educator-centred pedagogy with the use of technology that they are acquainted with while planning virtual courses. If this educator-centred pedagogy is unsuccessful, educators may need to change their tactics to see how the content can be represented using technology in a better way, which encourages the TPACK framework.

In addition to TPACK, I have also drawn on constructivism as a second underpinning framework. This is because, as previously stated, constructivism is a model of knowledge describing the processes of how human beings learn (Abdal-Haqq, 1998), and I have explored how the concept of cell biology is developed in students. In doing so, I employed Piaget's theory of cognitive development (Piaget & Cook, 1952) and Vygotsky's notion of the ZPD (Vygotsky & Cole, 1978). Piaget shows that intellectual growth is a process of adaptation through assimilation and accommodation. These are concepts relating to how students incorporate new knowledge into their existing knowledge structures. Students develop an understanding of cell biology concepts through a process of assimilation and accommodation of new concepts. When a student assimilates new knowledge, they are using their existing cognitive model, or schemas, to understand new knowledge (Piaget & Cook, 1952). Accommodation, on the other hand, deals with the conflict of the new knowledge to the existing schemas and involves how students change their existing schema to incorporate the new knowledge (Piaget & Cook, 1952). This theoretical framework was used to analyse how students' previous knowledge structures in cell biology influence the new knowledge that is presented to them at the university level through their responses to the assessment, as well as the interview questions.

The ZPD refers to the difference between what a student can do without help and what they can achieve with guidance from their lecturers (Vygotsky & Cole, 1978). Lecturers can assist students through the ZPD, as they are the More Knowledgeable Other (MKO), who is somebody who has a superior skill to comprehend information at a more advanced level. This can be done through the process of scaffolding. Scaffolding is a tool for growth in which students are given small, manageable steps in collaboration with an MKO to make connections between concepts (McLeod, 2019). Using the concept of the ZPD, I looked at lecturers' scaffolding process with the use of technology to enhance understanding of the cell biology concepts. In doing so, I was able to see how the lecturers may be able to help to mediate this process using technology. In other words, the ZPD, in addition to Piaget's theory of cognitive development and TPACK, was used to analyse how lecturers scaffold students' understanding of cell biology to enhance their understanding of what is expected at the university level. I evaluated how lecturers' use of technology may facilitate epistemological access, the effect of technology on how students receive and respond to the knowledge of cell biology, and whether previous exposure to learning with the use of technology has an effect on student learning through technology at university.

CHAPTER THREE

3.1. RESEARCH METHOD

The overarching research questions, and sub-questions, are suggestive of a pragmatic approach because this approach legitimises the usage of several methodologies in answering the research questions (Johnson & Onwuegbuzie, 2004). Both quantitative and qualitative methods were used in this research. The quantitative investigation, in the form of descriptive statistics was used in this study, and fundamentally concerns gathering statistical information to describe a specific phenomenon (Muijs, 2011). Quantitative data were collected from the prior knowledge and final assessment tests. Qualitative research is the study of the nature of a phenomenon (Busetto, Wick & Gumbinger, 2020). The qualitative data in the form of curriculum documentation, lecture data, interviews and questionnaires was analysed to explain patterns that emerged from the quantitative data.

According to the mixed methods design matrix by Johnson and Onwuegbuzie (2004, p.22), this research design would be termed a 'QUAL+quan', meaning that the qualitative and quantitative aspects of the research will run concurrently, but that the qualitative paradigm will be weighted more dominantly. I intended to provide both a thorough, explicit account of knowledge gaps that may exist in first-year medical students' conception of cell biology concepts and ways in which technology may be able to bridge these knowledge gaps.

Triangulation is an investigation approach used to assess the soundness of data through joining the outcomes from various data sources (Carter, Bryant-Lukosius, DiCenso, Blythe & Neville, 2014). Triangulation was achieved by explaining the patterns that emerge from the 2020 test results against the data collected by the lecturer interviews and by explaining patterns from the 2021 test results against the data collected by student questionnaires and the lecture data.

Other studies in this field have used different methods to both obtain and analyse their data. However, very few have used descriptive statistics as the majority of these studies aim to see the depth behind practices. From the mixed methods studies that I identified in my review of methods, qualitative data collection and analysis methods are weighted more than the quantitative (Kececi & Zengin, 2017; Gonzales, 2018; Dikmenli, 2010; Climer, 2011). There are limitations of a 'QUAL+quan' method; as it is weighted more qualitatively, the results of qualitative research may be biased. As such, I have tried to be aware of the potential influence of subjective views and remain conscious of such bias. Sourcing data from a variety of sources enhanced the reliability and validity of the results.

3.2. SAMPLING

Purposive sampling was used, which is a type of sampling that indicates that an informed decision was made about whom to include in the sample (Scott & Morrison, 2005). There were approximately 500 students registered for the course from which I sampled, and all registrants were provided with an invite to participate. Data were collected from thirty students in each of the 2020 and 2021 cohorts of first-year medical students who volunteered to participate in the study. In addition, interview and lecture data were collected from three lecturers who taught these students.

3.3. DATA COLLECTION AND ANALYSIS

Data were collected in block four of the 2020 academic year and over blocks two and three of the 2021 academic year. Data were collected in different blocks due to lockdown restrictions brought on by the COVID-19 pandemic, which made it difficult to collect data in 2020.

Year 1 (2020):

Document Analysis

Document analysis is a method for assessing official papers (Bowen, 2009). The CAPS curriculum documentation for the Senior Phase (Grades 7-9) for Natural Sciences (NS) and the Further Education and Training (FET) phase (Grades 10-12) for LS were analysed to inform me of the expectations of learners in high school. The first-year medical course outline at the South African university identified for this study was also analysed to inform me of the university's expectations of the students as they enter tertiary education. This method was used in conjunction with the other qualitative methods, as it is a good means of triangulation (Bowen, 2009; Carter et al., 2014).

Test and Exam-Equivalent Analysis

There were two prior knowledge tests given to students at the start of the course, and one exam-equivalent that was administered at the end of the teaching block. I looked at how questions were answered on the two prior-knowledge tests for the section on cell biology, and how the questions were answered in their final assessment, i.e. after the content was taught. I compared the test responses from students to the memos provided for all assessments. These sets of analyses were done to address research question 1. I have examined whether the questions were answered correctly or incorrectly. In addition, I allowed for moderately correct answers to evaluate how students' answers have changed after the knowledge had been presented to them after the course was complete.

Interviews

Three lecturers whose content focused on cell biology in first-year biology for the medical students were interviewed concerning their expectations in terms of prior knowledge of cell biology concepts of the students that they teach, as well as their use of technology in teaching. Answers to interview questions may indicate underlying philosophies in science teaching, so I thought that it might be useful in identifying lecturers' perceptions about knowledge gaps and use of technology to address research questions 1 and 2. Due to the COVID-19 pandemic, interviews were conducted on online platforms, i.e., Microsoft Teams/Zoom.

Lecture Data

Analysis was conducted according to an observation schedule and was comprised of observing the lecture material and activities that lecturers presented to students for cell biology, on the university's online platform. Other researchers in the fields of technology and cell biology teaching have used this method of research (Gonzales, 2018; Kececi & Zengin, 2017) as it is an authentic source of data. The limitation of this is that it covers a very small percentage of the work that goes on continuously in the environment. However, even though this interpretive method of data collection negates the likelihood of experimental generalizations, it is important to note that critical moments in a lesson may be indicative of underlying philosophies that may be viewed in any lesson with the same demographics.

Year 2 (2021):

Test and Assessment Analysis

Tests of the 2021 cohort of first-year medical students' were analysed in addition to those in the previous year for added reliability to address research question 1.

Questionnaire

Thirty students from the 2021 cohort were selected from the total that answered a questionnaire that I developed on Google Forms. The questionnaire enabled me to obtain reflections on their knowledge of cell biology, their impression of the use of technology to learn cell biology knowledge, their school history, and their university experiences, to address research questions 1 and 2. Questionnaires were chosen over written interviews due to COVID-19 restrictions, and the students' access to data, devices, and connectivity issues. This meant that students could respond when they were able to.

I marked the first prior knowledge test and analysed answers to determine the frequency in which students answered certain questions incorrectly, partially correct, or correctly based on their results, and presented them graphically. The second prior knowledge test was marked online by the MasteringBiology™ platform, which is an online resource that students can access via the university's learning management system. I have tabulated the percentage of students who got the answers correct and/or incorrect. Lastly, I marked the exam-equivalent to identify whether students were able to identify and correct misconceptions in a piece of writing, and have also presented this graphically. I used a thematic analysis to analyse the qualitative data. Thematic analysis is a technique for recognizing, analysing, and recording patterns within data, and was the basis of qualitative analysis for these data sets (Braun & Clarke, 2006). I had chosen to conduct a theoretical thematic analysis. A theoretical thematic analysis is driven by a researcher's theoretical framework or research questions (Braun & Clarke, 2006). The codes for the thematic analysis emerged from the data during my analysis.

All instruments were piloted and interviews were audiotaped for transcription purposes. Each datum set was coded so that themes could be elucidated according to theoretical thematic analysis. For the lecturer interviews and lecture data, similar themes were grouped and aligned with the research questions to determine lecturers' current practices in teaching cell biology concepts with the use of technology. I also looked at how each theme relates to the TPACK categories. The themes that emerged from the student questionnaires were grouped according to the research questions and compared to those of the lecturer interviews and students' responses to the tests and assessments. This allowed me to explain how lecturers and students perceive technology integration to enhance understanding. An analysis of the tests showed the accuracy of these perceptions. The transcripts and emerging themes were discussed with both supervisors to determine the validity of specific themes relative to each data set to see whether the themes suitably echoed the connotations apparent in the data sets. Discussions were also held on the interpretation of the data.

3.4. LIMITATIONS OF THE STUDY

COVID-19 restrictions contributed to the lack of data, as it was a significant obstacle in being able to interview students, as well as get more reliable data to conduct a more in-depth lecture analysis. The sample size was also a limitation in this study as only three lecturers were interviewed and this may not be indicative of a larger population. These limitations were borne in mind during the analysis and interpretation of the data.

3.5. ETHICAL CLEARANCE

I am a post-graduate student at the University of Witwatersrand and have to abide by all ethical standards as set out by the university, as ethical clearance has been granted. The university subscribes to the research integrity standards as set out in the Singapore Statement. According to the World Conferences on Research Integrity (2020) web page, the Singapore Statement states the responsibilities of the researcher under fourteen headings that include: integrity, adherence to regulations, research methods, research records, research findings, authorship, publication acknowledgement, peer review, conflict of interest, public communication, reporting irresponsible research practices, responding to irresponsible research practices, research environments, and societal considerations. Ethical clearance was granted for this study by the Central Ethics Committee of the university (Protocol Number: H20/05/15) (Appendix A).

Ethics is important to ensure that researchers balance the stresses employed as professional researchers in pursuit of something, as well as the civil rights and beliefs of the people that they are working with devoid of any risk and intimidation. For this reason, social research, such as in this study, demands the attainment of permission and approval of subjects (Cohen, Marion & Morrison, 2000). Consequently, information and permission letters were drawn up. The information and permission letter to the Deputy Registrar and Head of School at the university was sent (Appendix A) and both parties provided permission. Secondly, information and permission letters were drawn up for lecturers as they were observed and interviewed (Appendix B). Students who took part in the questionnaire also received information and permission notices (Appendix B).

Included in each of these letters was the title and purpose of the research, as well as what I will be doing concerning my data collection. Additionally, the participants were informed, as per ethical conduct requirements, of their anonymity and confidentiality being maintained in the research, and as such, all participants in the research are referred to using pseudonyms. In terms of data collection, subjects were informed that the data would be stored at the University of Witwatersrand for a period of three years before it is destroyed. Participants had the right to withdraw from the research at any point before this dissertation is provided for examination without the risk of penalty. Subsequently, the subjects were informed in the letters that the entire process was voluntary, and no incentives were given for participation.

CHAPTER FOUR

The present study was designed to explore first-year medical students' prior knowledge of cell biology and the potential effectiveness of technology integration in bridging the gaps. This is important, as it is a vital aspect of first-year medical students' understanding of cell biology. In this section, I present the data that was collected, recorded and analysed using descriptive statistics and thematic analyses. The findings that are included were then interpreted using the frameworks of constructivism and the TPACK model (Koeheler & Mishra, 2005).

4.1.1. FINDINGS AND DISCUSSION: PRIOR KNOWLEDGE

Curriculum Documentation

One of the key project focus areas was first-year medical students' gaps in conceptual knowledge. It was thus important to compare the CAPS documents with that of the requirements for first-year students. The results of these comparisons are presented in Table 1 below.

Table 1: Cell biology coverage per grade according to the CAPS curriculum in South African high schools.

GRADE	**CELL BIOLOGY CONTENT KNOWLEDGE COVERED IN SOUTH AFRICAN HIGH SCHOOLS ACCORDING TO THE CAPS**
8	*No aspects were covered for cell biology.*
9	Cell Structure; Differences Between Plant and Animal Cells.
10	Molecular Make-Up; Cell Structure and Function: The Roles of Organelles; The Cell Cycle including Mitosis.
11	*No aspects were covered for cell biology.*
12	DNA; Meiosis

In the CAPS document, the cytoskeleton is not mentioned as a concept on its own (DoE, 2012a). However, there are many aspects of the LS syllabus outlined in the CAPS document in which the concept of the cytoskeleton is taught implicitly (DoE, 2012a). In other words, there are sections in the high school syllabus in which the concept is taught concerning other processes without mentioning the cytoskeleton explicitly. These sections include mitosis, types of cells, and muscle tissue in the Grade 10 syllabus, and meiosis in the Grade 12 syllabus, as indicated in Table 1. In the Grade 10 syllabus, the section of cell biology begins with an overview of the organelles and cell components, and this does not include the concept of the cytoskeleton (DoE, 2012a).

Some organelles that are covered in the Grade 10 CAPS curriculum include the nucleus, mitochondria, plastids, endoplasmic reticulum, Golgi apparatus, and vesicles (DoE, 2012a). Even though the cytoskeleton assists in the movement and placement of these organelles, it is not outlined to be addressed to learners, which indicates that first-year students may not understand how certain cell components are structured, or how they function, as they are not exposed to the cytoskeleton. As such, when students enter university, they should have some knowledge of the cytoskeleton in context but would have had no explicit instruction on the concept. Explicit instruction on cell biology is therefore important, particularly for first-year medical students, as cell biology remains a key driver of all facets of biomedicine (Budde, Williams & Misteli, 2012).

The 'Introduction to Medical Science' student manual for Semester 1 was analysed to identify the work carried out with students during the course of the Semester. Students covered topics related to cell biology including cell organelles and compartments, prokaryotes, the cell membrane's structure and function, as well as the nucleus and cell cycle before moving onto histology. This shows that the lecturers had attempted to assist students' transition to university from high school in trying to address topics as though they were not studied in school. The manual includes a timetable for the course and a detailed breakdown of each topic for each section of the course. The manual additionally includes all the practical work and pre-lab work that students would engage in for the semester. The manual also contains learning objectives that contain prior knowledge questions such as differences between prokaryotic and eukaryotic cells, comparison of cytoskeletal structures, and the stages of a cell cycle.

This document analysis shows concerning results as the student manual for the Introduction to Medical Science for first-year medical students asks students as part of a prior knowledge question to tabulate actin filaments, microtubules, and intermediate filaments. Students may not be able to answer this, as they would have not covered this content in high school.

Prior Knowledge Tests

The prior knowledge tests were administered to students to determine the existing knowledge students have from prior exposure to topics in high school. In this course, two prior knowledge tests given to first-year medical students as part of their usual curriculum were analysed. The first test was a general one that covered the first-year syllabus for block one. The second test was specific to the section on cell biology only.

The 2020 prior knowledge test was conducted under test conditions and the 2021 test was conducted online due to the protocols of the COVID-19 pandemic. This general prior knowledge test on cell biology was followed by an online test that assessed the students' foundational knowledge on cell biology in more detail for 2020 and 2021. The 30 first-year students who were sampled in 2020 and 2021, respectively, were given a number so that their identities were not revealed when the data was captured for analysis. Only I was aware of the identities of the students. The findings of these prior knowledge tests are presented next.

1. *Prior Knowledge Test 1*

In the first prior knowledge test, students were asked seven general questions related to their prior knowledge from high school on the topic of cell biology as follows (quoted verbatim):

A: What content did you cover on the cytoskeleton at school?

B: What did you learn about the function of the cytoskeleton at school?

C: To what extent do you agree with the following statement: The cytoskeleton static (ridged).

D: Describe the structure of the cell membrane (plasma membrane).

E: Describe the function of the cell membrane.

F: To what extent is the cell membrane fluid (i.e. not static or rigid)?

G: Provide a definition for each of the terms below

- Ribosome – Organelle – Cytoplasm – Nucleolus - Cell Division

Figures 2.1 and 2.2 show students' responses to these questions. For the answers concerning content coverage, when there was no coverage of the topic as indicated by students, I have indicated this as 'None'. Concerning the question on cytoskeletal rigidity, students would have not answered the question if they had not covered the content at high school and this is indicated as 'N/A'. However, there is a misalignment between these two as some students still attempted to answer the question of rigidity even if they had not covered the content at school.

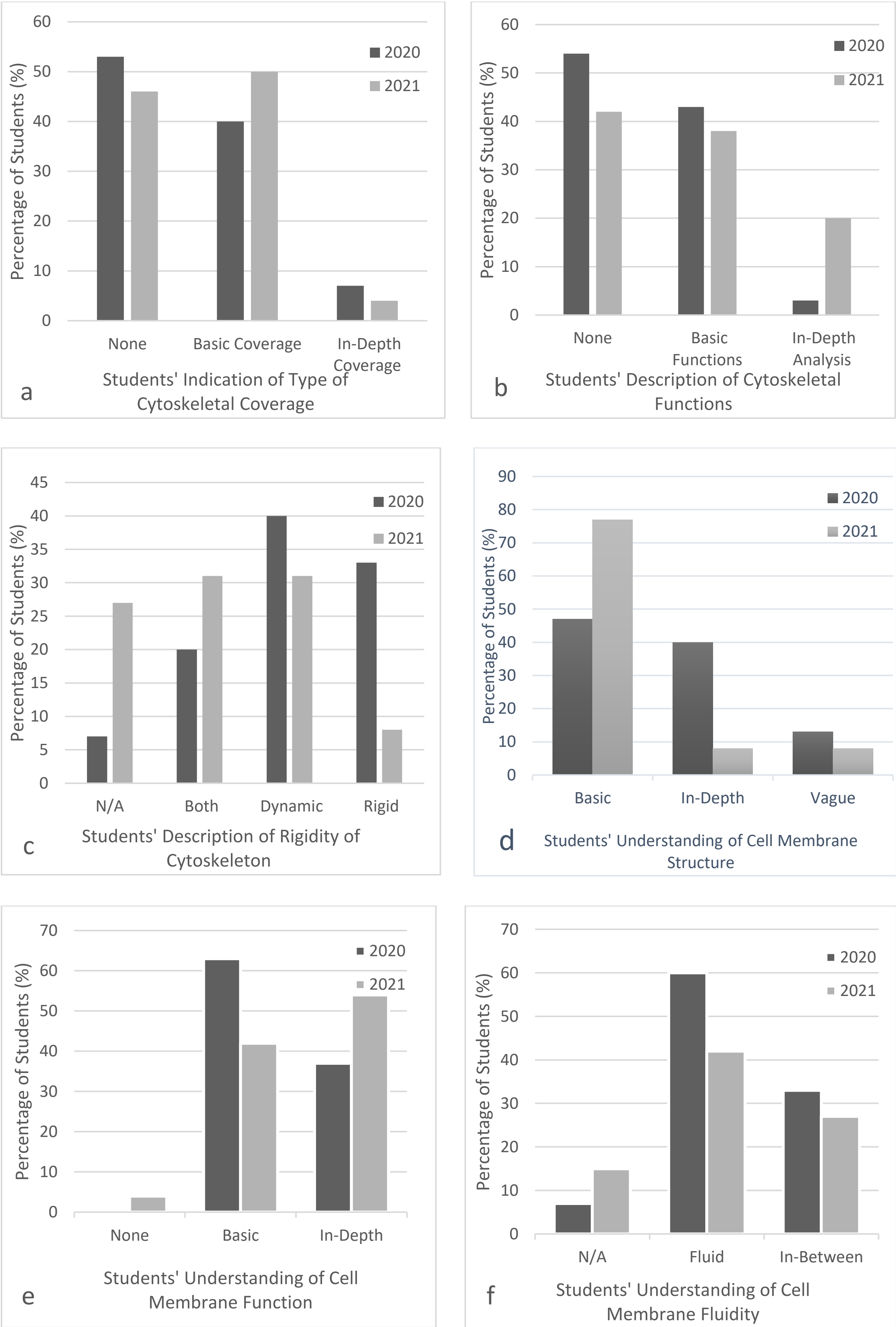

Figure 2.1.a-f: Answer Distribution for Prior Knowledge Test 1.

To identify the conceptual knowledge that students come into first-year with, to answer the first research question, it is necessary to look at the first prior knowledge test. 7% of students in the 2020 cohort and 4% of students in the 2021 cohort had indicated an in-depth coverage of the cytoskeleton (Figure 2.1.b). This suggests that most students have little knowledge about cytoskeletal concepts, which has implications related to the high school curriculum as it shows significant gaps in cytoskeletal knowledge that medical students require in their first year.

According to the first prior knowledge test results, more than half of the 2020 cohort and more than 40% of students in the 2021 cohort did not cover the cytoskeleton at high school. Students who have indicated that they have covered the cytoskeleton may have covered it implicitly through other sections in the curriculum, as it is not outlined in the CAPS syllabus to be covered at high school (Table 1). Additionally, students who were taught by teachers who covered sections in more depth as compared to what was indicated on CAPS might have possibly attained the knowledge from there. However, many students believed that the cytoskeleton is purely dynamic, which is only partially correct, as the intermediate filaments are more static components of the cytoskeleton (Figure 2.1.c). Climer (2011) states that some reasons that students have difficulties in learning certain topics in biology are because some biological events cannot be seen by the naked eye and that instructor-centred instruction could negatively affect learning. Considering that the cytoskeleton can only be seen when using an electron microscope, the abstract nature of this concept may affect student understanding.

Other than the vital component of the cytoskeleton, students have basic knowledge on parts of the cell that have been covered in high schools, such as the cell membrane. In CAPS, the cell membrane is the first cell component to be taught in Grade 10 (DoE, 2012a; Table 1). However, the majority of students gave basic answers for questions D-F in the first prior knowledge test, which refers to the structure and function of the cell membrane (Figures 2.1.d-f). 7% of students, in particular, did not understand the question of fluidity. One of these students replied that the cell membrane 'has very little fluid' and another stated that 'some parts…are more fluid than others'. I found this interesting as it points out that these learners' misconceptions may be due to the term 'fluid'. This is vital as Zukswert, Barker, and McDonnell (2019) state that correctly using discipline-specific vocabulary may be a particularly prominent hurdle in undergraduate biology. In other words, if the students are unable to make differentiations in their vocabulary, it may lead to their inability to grasp concepts. This has implications on both high school teachers and lecturers to ensure that students understand the language of science.

Figure 2.2 indicates the correctness of students' answers. 'Partially Correct' refers to students' who have accurate responses but are missing some information to get the answer fully correct.

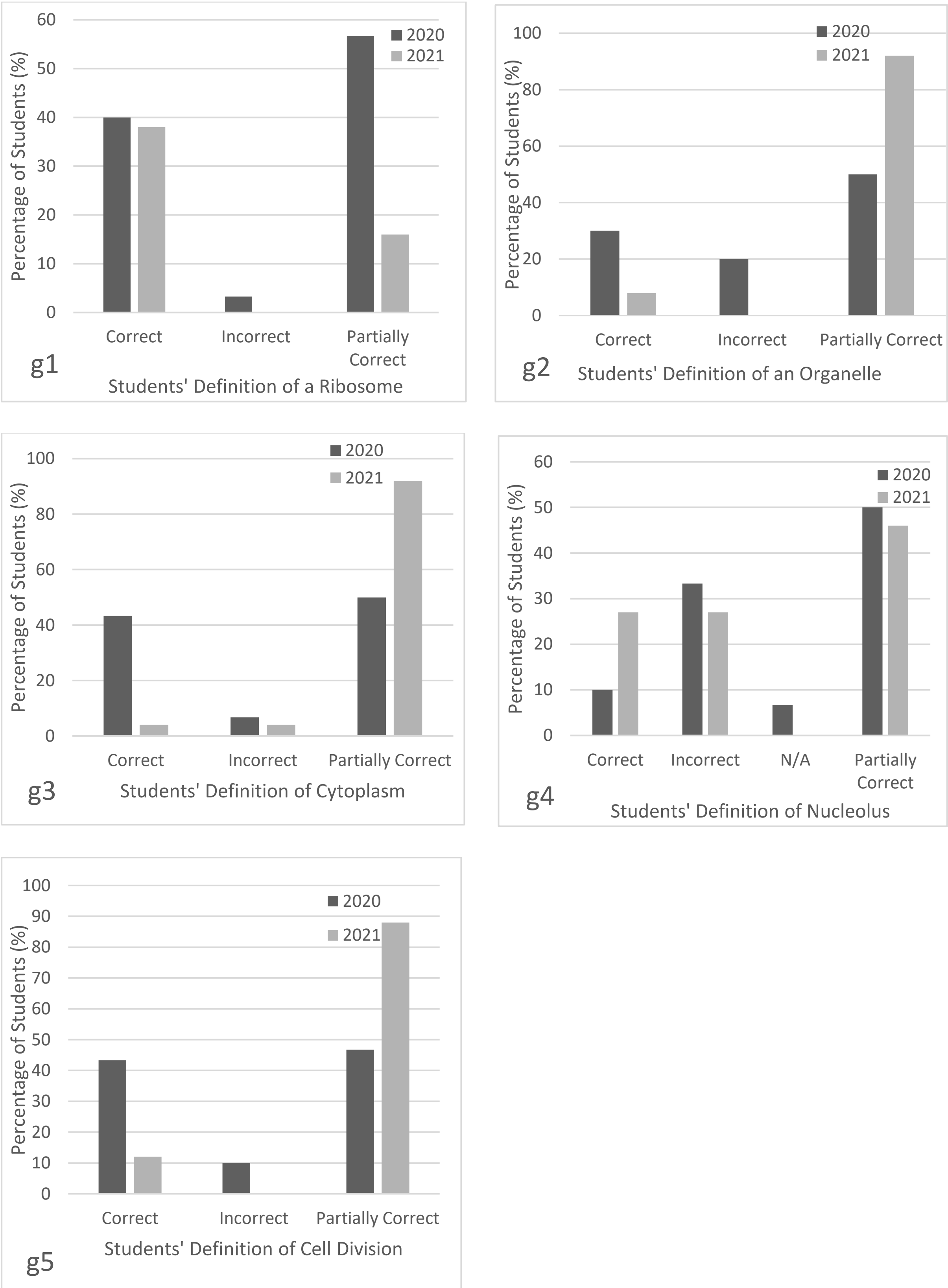

Figure 2.2: Answer Distribution for Prior Knowledge Test 1, Question g.

Looking at Figure 2.2, the majority of students in both cohorts could not give full descriptions in the first prior knowledge test. For example, with the term ‘organelle’, less than half of the students (30% in 2020 and 8% in 2021) could correctly define what an organelle was as per the memo in Appendix D (Figure 2.2). Among the 20% of these students that answered incorrectly, some stated that organelles were organs within cells. Further misconceptions were noted with the definition of nucleolus where 13% of students in the 2020 cohort confused the nucleolus with the nucleus. Many of these misconceptions may be due to terminology as the words are quite similar in spelling. A lot of the student answers for these questions are generic answers that seem to come from memorization rather than understanding as responses were similar but incomplete. This has implications for curriculum design, because, as stated earlier, overloaded curricula may lead to memorization rather than understanding (Climer, 2011).

Secondly, regarding cell division, many students could correctly give a definition discussing the process of cell division. However, less than 44% of the 2020 cohort and 12% of the 2021 cohort could correctly outline what cell division entails (Figure 2.2). This would then also have implications for the student manual as lecturers may have to look at the results to this question and align the university curriculum to the high school curriculum. This could be done in a way to scaffold students’ knowledge of cell biology from their high school knowledge to what is expected of them at university. This scaffolding, provided by the lecturer in the form of the prescribed syllabus detailed in the student manual, could support the students as they are led through the ZPD.

While the first prior knowledge test examined the foundational understanding of students, the second prior knowledge test was conducted closer to the time of teaching this section on cell biology. Whereas the first prior knowledge test contained mostly open-ended questions and a table that required students to define terms, the second prior knowledge test was multiple-choice and provided online via the MasteringBiology™ platform.

2. *Prior Knowledge Test 2*

The questions for the second prior knowledge test were more specific compared to the broad, first-prior knowledge test. This second one aimed to determine the gaps in student understanding and the misconceptions that existed, as shown in Table 2. Therefore, these questions more closely examined student knowledge on concepts such as the cytoskeleton. The 2021 cohort of students answered both prior knowledge tests online due to the move to online learning because of the COVID-19 pandemic regulations.

Surprisingly, apart from the question on organelles, the 2021 cohort of students did worse than the 2020 cohort in this test, particularly on the question regarding the cell membrane. This is surprising as the content knowledge taught at high school and expected in this test was the same for both cohorts of students.

Table 2: Answer distribution for prior knowledge test 2

Question Topic	2020		2021	
	% Correct Answers	% Incorrect Answers	% Correct Answers	% Incorrect Answers
A: Cytoskeletal Structures	93	7	N/A	N/A
B: Cytoskeletal Fluidity	90	10	62	38
C: Cilia and Flagella	90	10	86	14
D: Cell Junctions	85	15	69	31
E: Cell Membrane	43	57	7	93
F: Organelles	54	47	80	20
G: Motor Proteins	100	0	59	41

Most students in the 2020 cohort (93%) got the answer for A correct. The question in the test reads as follows, ' Which statement about the cytoskeleton is true? *Microfilaments are more permanent structures in cells compared to intermediate filaments and microtubules./Microtubules are chains of proteins that resist stretching./Components of the cytoskeleton often mediate the movement of organelles within the cytoplasm./Intermediate filaments are hollow tubes of protein that provide structural support./Plant cells lack a cytoskeleton because they have a rigid cell wall.*' The students that got the question incorrect chose the answer that relates to the plant cell. This option in the test is the only one that includes content that was taught at high school as it relates to the cell wall being the support structure of a cell. In the CAPS document, the cell wall is defined as a "support structure in plant cells only" (DoE, 2012a, p.25) and the students in my study may be holding preconceptions of the cell wall of the plant cell, which they have applied to this context. A similar question was not asked in the 2021 second prior knowledge test.

Secondly, 15% of students in the 2020 cohort and 31% of students in the 2021 cohort did not answer the question on cell junctions correctly. This question includes subject knowledge that was not taught implicitly or explicitly in the CAPS syllabus; therefore, students did not have the prior knowledge to interpret the question, and consequently, did not do well.

However, answers to topics covered in high school also showed evidence of vague ideas or misconceptions. One question that many students had difficulties with is question E that concerned the structure of the cell membrane (Table 2). In CAPS, the cell membrane is outlined in the detail needed for this question in the Grade 10 curriculum (DoE, 2012a). However, more than half the students (57%) were unable to answer this question in the 2020 cohort and 93% of the 2021 cohort (Table 2). This shows that there is a gap in conceptual knowledge of the cell membrane and its functions. This implies how students are able to adapt new knowledge structures. Students' inability to understand the structure of the cell membrane may be due to their inability to visualize the fluidity and processes that can occur across the cell membrane. Stith (2004) offers support for this point using the example of movement through the cell membrane to explain how this process is difficult to explain with the use of static illustrations.

The next question that students in the 2020 cohort struggled with was question F. For the 2020 cohort, students were asked about the composition of various organelle membranes with reference to each other, and almost half of the students were unable to differentiate between them. Considering that students also struggled with questions on the structure of the cell membrane in the first prior knowledge test (Table 3), it can be assumed that students have preconceptions of the cell membrane, as well as organelle membranes, which are not founded in scientific knowledge as they struggle to answer basic questions on structure and function.

Online Exam Equivalent

At the end of the course, an online exam equivalent was given to students to evaluate the content that was taught. This was analysed to see whether the prior content knowledge that students entered into university with (indicated in the two above sections) had altered in any way. In the online exam equivalent, i.e., after the content was taught in first-year, students were given a test that consisted of paragraphs that included misconceptions about various cell biology content. This assessment is pitched at a different cognitive level as opposed to the prior knowledge tests as performance here demonstrates student's development of content understanding. Due to the lack of conceptual knowledge on the cytoskeleton and membranes, the misconceptions that this research project focussed on were:

1. How Cytoskeletal Parts Work. 2. Make-Up of Cytoskeletal Parts. 3. Cell Junctions. 4. Membrane Structure. 5. Endomembrane System. If students were able to correctly identify and correct the misconception in each instance, it is indicated as such. If they did not identify the misconception or part of the misconception, this is indicated as 'not identified'. The answers are indicated in Figure 3 below.

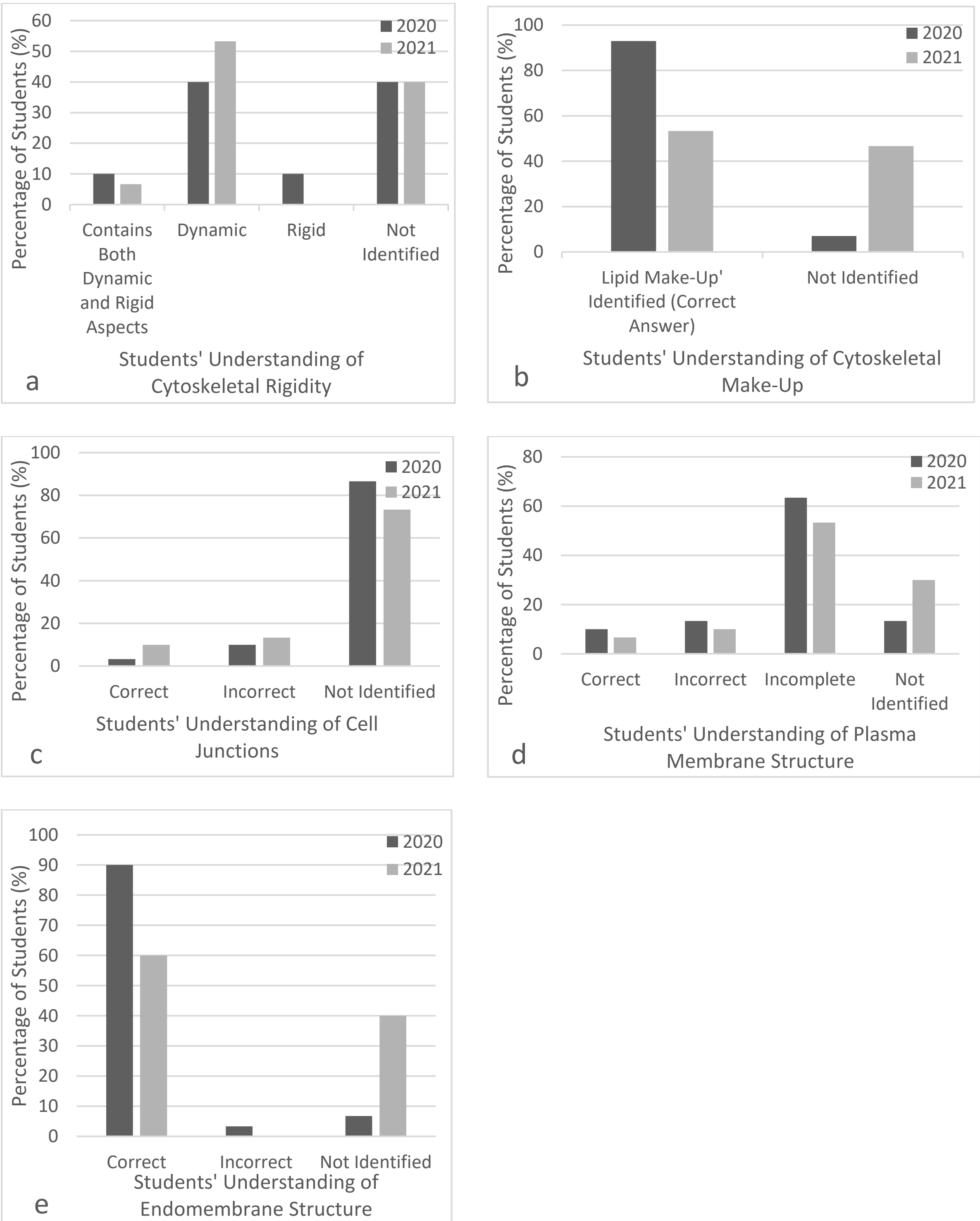

Figure 3 a-e: Students' Understanding of Cell Biology Identified in Online Exam Equivalent.

The findings in Figure 3 suggest that students were largely unable to identify misconceptions relating to the cytoskeleton, cell junctions, and membranes. For the 2020 cohort, only 10% of these students got the answer fully correct in identifying the parts of the cytoskeleton that are more rigid and those that are more dynamic (Figure 3a). Only 3% of students had correctly identified both from the beginning. Further, only 7% of students have changed their conception of the cytoskeleton. Another acceptable answer relating to the first misconception is that the cytoskeleton is dynamic. However, only 40% of students in the 2020 cohort answered in this way (Figure 3a). This percentage is the same in the first prior knowledge test. When comparing the final assessment to the second prior knowledge test, a decrease in numbers is evident as the correct number of answers in the second prior knowledge test was attributed to 90% of students.

Additionally, 40% of students in the 2020 cohort did not identify the misconception regarding cytoskeletal fluidity in their answers. Misconceptions concerning cytoskeletal elements were indicated by words such as "*stable", "rigid"* and "*lipid"*. Where students did pick up the protein make-up of the cytoskeleton fibres, only 10% of students in the 2020 cohort and 7% of students in the 2021 cohort had noticed the error concerning the structure correctly. 10% of these students in the 2020 cohort held this misconception in prior tests. This is because students had stated that the cytoskeleton is a permanent structure in the second prior knowledge test and one student, in particular, said that the structure was rigid in the first prior knowledge test, which shows that there was no development in this student's conception of the cytoskeleton.

Only 3% of students pointed out and corrected the misconceptions concerning cell junctions fully in the final assessment for the 2020 cohort and only 10% of students in the 2021 cohort (Figure 3). As this is not a concept introduced at the high school level, it should have been developed at university. According to Longfield (2009), we have a natural inclination to stress information that supports our existing schemes and discount information that would create instability in our understanding. Therefore, since these students did not seem to have the existing knowledge of cell junctions, they may have struggled to adjust any current knowledge structures concerning cell biology, even after being introduced to alternate conceptions.

In addition, the majority of students struggled with membrane structure. Less than 10% of students in both cohorts managed to correct the misconception that stated that organelle membranes comprise a single layer of phospholipid. The majority of students corrected the misconception only partially, as after stating that it should be a phospholipid bilayer, they failed to mention exceptions such as the nucleus, which is a double membrane structure (Figure 3d).

Another misconception was also prevalent in the 2021 cohort of students, as 10% of students had confused bi-layer with a double membrane. Of this 10%, one of these students had stated in the first prior knowledge test that he did not learn about the concept of the cell membrane in school. However, the CAPS curriculum document analysis shows that this should not be the case (DoE, 2012a). This inconsistency indicates that the student might have had difficulty grasping the concept at both high school and university levels.

Interviews with Lecturers and Lecture Analysis

In addition to the prior knowledge tests that were given to students to get an understanding of their prior knowledge on cell biology, three lecturers were interviewed about their understanding of student prior knowledge and its implications on how they teach new knowledge at the university level. The main themes were derived from these interviews according to the research questions. The three lecturers had also provided me with lecture resource material and activities that were put onto the students' online learning management platform.

- Mrs. Dlamini provided me with four sets of presentation slides used for four lectures as well as practical and homework activities.
- Ms. Nkosi provided me with source material from the online software that is used by students.
- Mr. Zambo provided me with two sets of presentation slides used for two lectures that included activities.

Six main themes were derived from the analysis of the interviews and lecture analysis. Two of these are tabulated below with the TPACK categories that fall under them, in order of how strongly the category is presented in the data (Table 3).

Table 3: Main themes derived from interviews and lecture analysis

Theme	**TPACK Categories**
Scaffolding	Content Knowledge Pedagogical Knowledge Pedagogical Content Knowledge
Pedagogy	Content Knowledge Pedagogical Knowledge Pedagogical Content Knowledge

1. Scaffolding

Scaffolding is an instrument in which students are given small, practicable steps in partnership with an MKO, to create links amid concepts (McLeod, 2019). In the interviews with lecturers, emphasis was placed on school content knowledge and the lecturers' awareness of high school syllabus coverage. All the lectures had reported their perception that cell biology and histology content knowledge is 'not detailed' or that there is 'no detail' taught at the high school level. This perception was shown in the lectures that were analysed as lecturers had prepared slides that accommodates for students who may not have prior knowledge of the topics, ranging from everyday knowledge of concepts to more abstract knowledge. However, as the PowerPoint presentations did not have voiceovers and were provided on the online platform in this form due to the COVID-19 pandemic and the shift to emergency remote teaching, there was limited lecturer interaction with students' specific misconceptions. Nevertheless, general misconceptions were addressed with the use of activities and videos to enhance understanding.

2. Pedagogy

Due to COVID-19 pandemic restrictions, the majority of instruction occurred on the university's online platform. Therefore, Mrs. Dlamini and Mr. Zambo had prepared PowerPoint-type slides and had put this onto the students' online platform for students to access. These slides were heavily text-based. This approach is instructor-centred and will be unlikely to cultivate understanding (Elkindir, 2020). Ms. Nkosi had given students various microscope slides to look at using an online simulation that replicates microscope use. It is important, therefore, to note that apart from Ms. Nkosi's practical viewing of slides, the other two lecturers had taught the content using lecturer-centred approaches as the content was put onto slides that were given to students. The only student-centred learning that Mr. Zambo had agreed on was positive in terms of technology, use was the 'online discussion' as he had stated that it 'promotes group learning' and 'own critical thinking'. During the interviews, it became evident that lecturers were aware that the content is not covered in detail at the high school level and that this caused misconceptions and limitations in students' content knowledge as well as their skills development, which is seen in the students' results for the prior knowledge tests. Ms. Nkosi also said that students cannot '…identify the different types of epithelial cells…' and that they do not know '…how to calculate actual drawing of a cell, and preparing a scale for a drawing.' She also said that 'Some have never handled a microscope in all their lives which makes things pretty hectic'.

Questionnaire Responses from Students

The focus for data collection in 2020 was to see the students' potential knowledge gaps and changes in conceptual knowledge with the use of technology at the university level. Based on the data collected in 2020 it became evident that more probing was required to establish students' perceptions of this journey as the 2020 data did not look at students' perceptions of their learning. Therefore, it was considered necessary in Year 2 of data collection to include responses from students on these aspects, and questionnaires were the most appropriate means to gain insight into these areas.

The thirty, first-year medical students, in the 2021 cohort, participated in a questionnaire to explore their prior knowledge of cell biology and the potential effectiveness of technology integration in bridging any the gaps. These students fall between the ages of 18-25 and have all done Life Sciences at the high school level. Students were asked questions on their perceptions of cell biology and the use of technology to aid their learning. Their answers were grouped according to the research questions to derive themes in answers. Themes for the first research question are indicated below.

Table 4: Main themes derived from open-ended questions in questionnaire.

Research Question 1	**Themes Derived From Research Question Based On Students' Answers**
To what extent are there knowledge gaps between high school and first-year university knowledge on the topic of cell biology?	Difficult Concepts Representations

1. Difficult Concepts

More than a quarter of the students who answered the questionnaire had indicated that cell biology, as a topic, is difficult for them to conceptualize, which is similar to the students in Climer's (2011) study. Specifically, two students mentioned aspects such as the 'Components of the cell membrane' and 'the process of protein synthesis (translation)…' as difficult to understand. Some students had indicated in the questionnaire that cell biology, immunity, and protein synthesis are problematic for them to grasp and have attributed their lack of conceptual understanding to several factors. Amongst these factors, students have indicated that visualization, workload, lack of lecturer support, and too many new topics made this topic challenging to understand.

Additionally, students have indicated that there are topics at university that were not introduced to them in high schools such as cell processes and organelles, including the cytoskeleton. This is important, as topics not covered at the high school level may have to be taught by lecturers before expanding on the new knowledge that was meant for students at the university level.

2. Representations

Students indicated that high school teachers had used various representations in teaching cell biology. Over 40% of students who had indicated that their high school teacher used technology to teach them cell biology had used projectors, PowerPoint presentations, and smartboards in which students were shown images and videos. Other teachers had taught students how to view slides with the use of a microscope. In some schools where there was a lack of technology, teachers had printed images of cells for students or use images from the textbook for visualization. Representations are important to enhance learning (Veselinovska, et al., 2011).

4.1.2. FINDINGS AND DISCUSSIONS: TECHNOLOGY

Another of the key project focus areas was the possibility of technology integration in assisting to mitigate knowledge gaps.

Interviews with Lecturers and Lecture Analysis

In continuation from Table 3, the following four themes were derived from the interviews and lectures that related to technology use.

Table 5: Main themes derived from interviews and lecture analysis

Theme	**TPACK Categories**
Engagement	Pedagogical Knowledge
Applicability of Technology	Technological Knowledge Technological Pedagogical Knowledge
Visuals	Pedagogical Content Knowledge Technological Content Knowledge
Preparedness	Technological Pedagogical Knowledge

1. Engagement

Lecturers mentioned in interviews that they miss student engagement since instruction moved online. Mrs. Dlamini mentioned that although communication does exist it is ‘not as effective as face-to-face interaction’. Ms. Nkosi and Mr. Zambo also commented on the human element.

Ms. Nkosi stated that ‘we are social beings and feel…more at ease when interacting with students. Mr. Zambo echoed this by stating, ‘I do miss the in-person engagement with the students’. These statements indicate that the philosophies that underpin their teaching are largely social. Social teaching methods are innovative and are related to constructivism as knowledge is constructed through these interactions (DiCarlo, 2006).

2. Applicability of Technology

Mrs. Dlamini and Mr. Zambo used the online platform to provide students with the content for the course using PowerPoint-type slides with text, images, and videos. While it was scaffolded by moving from everyday knowledge to scientific knowledge, there were no voice-overs or text explanations, which is important to clarify conceptual knowledge (Crawford, 2021). The TPACK component of TPK (Table 5) indicates the importance of finding ways to teach content that is applicable to the content. For example, Ms. Nkosi had provided students with activities in which they had to engage with microscope slides using an online simulation. In her interview, she had stated that although this assists in students’ ability to identify items under a microscope, it was not providing them with the skills necessary to use a microscope as some students may have not had this experience at their high schools either.

3. Visuals

All three lecturers stressed the importance of visuals in assisting students to understand abstract concepts in biology. Mrs. Dlamini and Mr. Zambo had included many images and videos in their PowerPoint presentations. Ms. Nkosi also stressed this importance in explaining the online microscope simulation, as she also believes that it is important for students to visualise the content at this representation level. Introducing learners to images of cells is important to make concepts more concrete (Kapici and Savasci-Acikalin, 2015).

4. Preparedness

When asked about the learning platform for students, Ms. Nkosi replied, ‘We were not ready!’ What was equally concerning is that all the lecturers indicated having had access to training to adapt to the digitalized curriculum but Ms. Nkosi had admitted that she did not take advantage of the opportunity. Additionally, all three lecturers had implied that in-person teaching is preferable and that they are not adequately equipped to conduct lessons for all facets of the curriculum. Unfortunately, insufficient acceptance of the digitalized syllabus can compromise the value of teaching and learning (Khosa and Mpungose, 2020).

Questionnaire Responses from Students

Figures 4.1-4.4 below represent answers that were derived from four closed-ended questions that were asked to the 2021 cohort of students about technology integration as follows:

1. Did your school have a technological infrastructure? (Software, equipment, facilities, and structures)

2. In what year did you matriculate?

3. Did you find that the online learning resources were guided or did you feel as if you were self-taught?

4. What do you mainly use technology for?

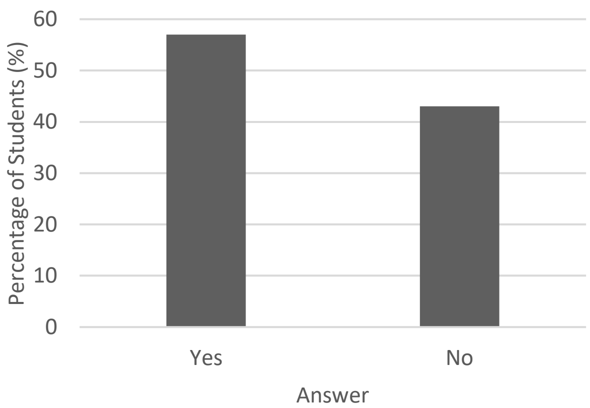

Figure 4.1: Students' Indication of Presence of High School Technological Infrastructure

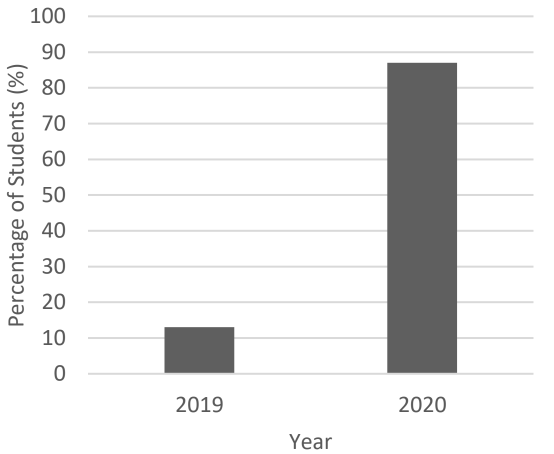

Figure 4.2: Year In Which Students Matriculated

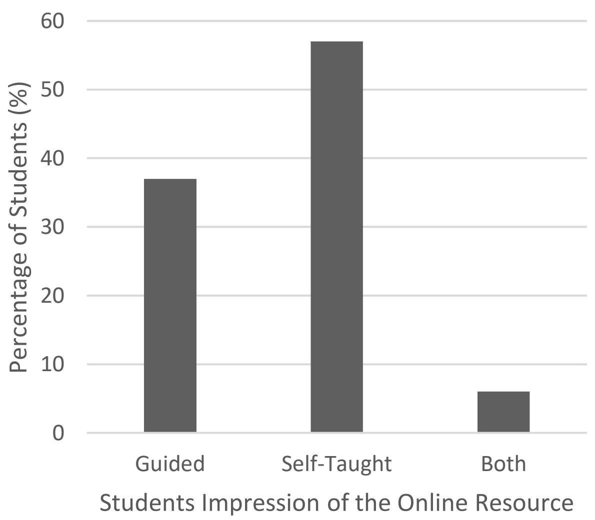

Figure 4.3: Students' Impression of the University's Online Resource

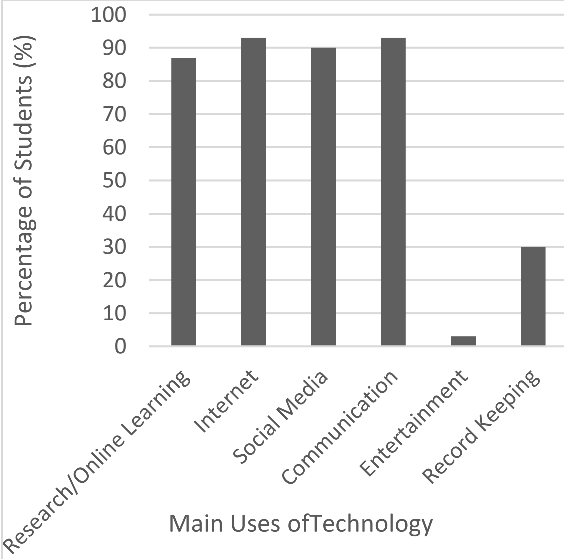

Figure 4.4: Students' Indication of Their Main Technology Usages

Students were also asked questions on their perceptions of technology use. Their answers were grouped according to the research questions to compare themes that emerged previously, as in Table 4. The findings of this grouping in relation to technology use are shown in Table 6 below.

Table 6: Main themes derived from open-ended questions in the questionnaire.

Research Question 2	**Themes Derived From Research Question Based On Students' Answers**
How do students and lecturers perceive the integration of technology in enhancing the students' understanding of cell biology?	Practice and Experience Limitations

1. Practice and Experience

Seventy percent of students, particularly those who matriculated in 2020, have had experience using technology for learning at high schools, such as online lessons, Microsoft Teams, YouTube, and WhatsApp, as well as for research reasons. Students have indicated benefits of technology with statements such as, 'It helps improve understanding and visualisation', 'You can actually visually illustrate a concept, because cell biology isn't something necessarily for the naked eye to see'. One of the students had stated that 'To fully understand how components of cells look like and how certain processes occur in cells, one would need to see those processes occur (unless you have an impeccable imagination).' I concur with what students have stated here as the literature (Kiboss et al., 2004) also points towards the use of technology to visualize abstract concepts. The students' views also aligned with the views of lecturers. For instance, all three lecturers emphasized in their interviews, the need for visuals in the forms of images, videos, and microscope work to address misconceptions.

2. Limitations of Technology

There are a few limitations of technology that students had indicated which included lack of skills development, lack of practical aspects, and poor connection - similarities found in Mpungose's (2021) study. Only 56.7% of students have indicated that their school had technological infrastructure (Figure 4.1). These students who had access to technology said that their teacher at high school taught them using various technological tools as indicated earlier. Students who did not have access to these technological structures have stated that their teacher would either use the textbook or give them handouts in an attempt to bridge the visualization gap. However, lecturers may need to fill in any gaps in understanding due to students coming into university with a view of the cell limited to what can be seen in images.

Although this may not provide learners with an understanding of the dynamic or three-dimensional properties of cell biology, for Kapici and Savasci-Acikalin (2015), images in science textbooks play a significant role in combatting some notions that learners have. Additionally, while these students may have not had access to technology at the high school level, many had indicated that they use technology for online learning, and research purposes, and have reported in the questionnaire that their technology usage for studying is positive, apart from the occasional 'connection problems' (Figure 4.4).

In general, students agreed that technology had assisted them to adapt to new knowledge, which included the resources that lecturers had put on their online portal for them to access. From the questionnaire results, the majority of the students (86.7%) had an experience of using online resources. This could be attributed to the fact that this cohort of students matriculated in 2020, where much learning was online (Figure 4.2). However, more than half of these students (57%) had stated that the online learning resources provided by their lecturers did not give them enough support as they felt as though they were self-taught (Figure 4.3). This is concerning as Mr. Zambo had indicated that the 'university and faculty have provided workshops' but, according to Ms. Nkosi, she did not access these professional training opportunities. This showed that, although all three lecturers displayed some proficiency in both the TPACK spheres of content knowledge and pedagogical knowledge, they lacked the necessary proficiency in technological knowledge, which may have hindered their technologically based lessons, and affected learning and performance of students in the assessments.

Students have indicated, however, that the use of technology is beneficial to their understanding of cell biology as it assists in their visualization of abstract components and processes. Additionally, they state that they benefit from researching and watching videos on concepts that they do not understand. However, as stated by Ms. Nkosi, the technology use limits students' practical ability, and students' responses showed that they have a similar view. Climer (2011) also agrees upon this as his study suggested that practical work encourages learner-centeredness and interaction and, as the learners in his study pointed out, educators may achieve more learner involvement and intrinsic motivation to learn if the classroom environment is made more interesting. This is important, as students need to comprehend their discipline's epistemological core. This means that not only do first-year medical students need to understand the theory of their discipline but the practical component is just as important to give them the skills necessary for them to achieve holistic epistemological access.

4.2. INTEGRATED DISCUSSION

From the document analysis and the prior knowledge tests, I was able to gather a gist of the content knowledge that is taught to learners at high school and compare that to the knowledge that students are expected to have at first-year university, which helped me to answer research questions 1a and 1b. Comparisons of the prior knowledge tests to the answers in the final assessment helped me to answer question 1c. Questionnaires with students and the interview and lesson data from lecturers helped me to gain insight into the potential effectiveness of technology integration in bridging content knowledge gaps, which helped me to answer the second research question, and successive sub-questions. Each data collection tool produced interesting results, and when these were analysed, there were various implications for teaching and learning.

Life Sciences (LS) is not a requirement for students to study medical sciences at the university where this study took place. This would mean that students who do not choose to take LS at high school level would have last engaged with cell biology in Natural Sciences (NS) in Grade 9 (Table 1). Unfortunately, the NS curriculum is given a short timeframe, as the curriculum outline also includes aspects of physical sciences to be taught to learners (DoE, 2012b). Therefore, it does not account for an in-depth understanding of cell biology concepts. Furthermore, should students choose to take LS as a subject at FET level, the section on cell biology is given a period of less than a term to cover, which is also a significantly short time frame to conduct a detailed exploration of cell biology (DoE, 2012a). According to Climer (2011), teachers in these cases try to teach the content hurriedly to cover all the required topics rather than engaging the students which may consequently lead students to study the content through memorization. This is important to note as it implies that although the students may have some grounding in the content, they may not have developed an understanding of the concepts that they can recall. As stated earlier, rote memorization of facts limits students' conceptual understanding (Momsen et al., 2010). In a study by Sung et al. (2020), students used different approaches to answer questions on genetics that were not based on scientific knowledge and understanding. Their study revealed that some students developed problem-solving methods to answer questions, such as finding apparent patterns formed in multiple-choice assessments (Sung et al., 2020). This is concerning as it shows that when students place their emphasis on lower levels of thinking, it may impede on a more complex understanding of phenomena as they may put minimal effort into developing their understanding of important concepts.

In the first prior knowledge test, which was written under test conditions for the 2020 cohort, 40% of participants said that the cytoskeleton was dynamic in nature (Figure 2.1). This percentage increased to 90% of participants in the second prior knowledge test, which was conducted online (Table 2). These results may show that students may have used the internet to search for answers as the test occurred online. This possible use of technology questions the academic integrity of the assessment, as the results for the second prior knowledge test are much higher than that of the first prior knowledge test for this cohort. This may be intensified by the fact that many of the students in the 2020 cohort say that did not cover the cytoskeleton at school in the first prior knowledge test (Figure 2.1) but got many of the answers correct in the second. However, in the final assessment, this percentage dropped back down to 10% of students able to give the correct answer (Figure 3a). Therefore, the use of the internet to assist in answering questions may have not assisted in students developing conceptual understanding.

Another example of the lack of academic integrity is the last question of the second prior knowledge test. The question is concerning motor proteins interacting with the components of the cytoskeleton. For this question in the 2020 cohort, all the participants got the answer correct (Table 2). However, the curriculum documents show that this is not taught at high school level (DoE, 2012a). This is further illustrated by the fact that more than half of these students in the first prior knowledge test admitted that they did not cover the concept at high school level (Figure 2.1).

The probability of students gaining correct answers using other resources is high as even the 53% of students who did not cover the concept at high school could answer the question correctly (Figure 2.1, Table 2). This is interesting as the intention of prior knowledge tests to serve as diagnostic assessments might not be met if students are using other resources to assist them to provide an answer to the assessment. This is demonstrated in one instance in the 2021 cohort, where a student had indicated on the answer paper that he did not learn these concepts in high school and thus, ‘looked them up’.

This is important, as when looking at the results of the final assessment as compared to the prior knowledge test, it became apparent that knowledge gaps still exist, not only in content that was not taught at the high school level but for some concepts that were addressed in the first-year university course as well. This behaviour is suggestive of a focus on grades rather than the development of conceptual understanding, a well-known phenomenon in assessment literature.

This is because schools and the wider society place great importance on grades, which socializes students into passing subjects rather than understanding. Only occasionally is an effort put into gaining the required understanding (Farias, Farias & Fairfield, 2010). To address this issue and shift student mindsets, school and university curricula should place greater emphasis on the creation of strategies that endorse collaborative ways of knowledge acquisition, which may reinforce the attention to learning rather than achievement (Farias et al., 2010).

Constructivism has significant inferences for teaching, syllabi, and policy, as it encourages the usage of instructional resources to ensure that students are vigorously involved in learning content (Schunk, 2012). Vygotsky's sociocultural theory stresses the societal environment of students as critical for knowledge acquisition (Schunk, 2012). Another key point in his theory is the concept of the Zone of Proximal Development (ZPD). Based on Vygotsky's explanation of the ZPD (indicated in an earlier chapter), his theory indicates that knowledge development is due to social facilitation (Schunk, 2012). Thus, the lecturers play a vital role in guiding the students along a pathway to the cell biology knowledge that they need. To do this, the lecturers need to scaffold the required knowledge to match the students' current state of development by arranging activities that will support them to engage and develop in their competence.

As evidenced in this study, the quality of prior knowledge influences students' ability to understand new knowledge. Prior knowledge is important for students as Piaget shows that intellectual growth is a process of adaptation through assimilation and accommodation (Piaget & Cook, 1952). In other words, students construct their new knowledge based on their prior knowledge constructs and this becomes more difficult if there is no relevant prior knowledge to base the new knowledge on. These practices correspond with one another; as new information is assimilated, structures are accommodated. As such, the development of reasoning will be able to happen simply after a mental conflict occurs. This is because knowledge acquisition happens once children experience mental conflict and engage in assimilation or accommodation to create or change internal structures (Schunk, 2012). The importance of prior knowledge is highlighted in the study. Lecturers need to be cognisant of the prior knowledge that students enter university with and use this as a stepping-stone to create activities that will conflict with students' prior knowledge to develop deeper reasoning of cell biology concepts.

In other words, instruction must follow at university towards disrupting the students' mental constructions by introducing concepts that are slightly more complex than that of their prior knowledge. Once equilibrium between these two conflicting knowledge structures is reached through assimilation and accommodation, a resolution will bring about a new understanding. However, it is important to note that the material must not be readily adapted, nor too challenging, as this could prevent accommodation (Schunk, 2012). This means that, if the new knowledge is too easy or too difficult for the students, they may be unable to resolve the mental conflict, which will result in no new knowledge being internalized.

As stated earlier, we have a natural inclination to stress information that supports our existing schemes and discount information that would throw us into disequilibrium (Longfield, 2009). Therefore, it is possible that since the students in this study did not have the existing knowledge of certain concepts, such as cell junctions, they struggled to adjust any current knowledge structures concerning cell biology, even after being introduced to alternate conceptions.

Climer (2011) states that students have difficulties in learning topics in biology because some biological events cannot be seen by the naked eye and that instructor-centred instruction could negatively affect learning. Considering that the cytoskeleton can only be seen using an electron microscope, the abstract nature of this concept may affect student understanding. However, as shown, the test results have indicated that students are not only unable to answer questions based on content that was not taught at school, but they are similarly unable to answer questions based on content that was taught explicitly in the Grade 10 syllabus (Table 1, Table 2, Table 3). This is concerning as students were unable to correctly define the structure and function of various cell components, particularly the cell membrane. The findings thus suggest the existence of knowledge gaps for this component when students enter university. Lecturers, therefore, may need to be aware of students' inability to understand the structure and fluidity of membranes and may have to use simulations and animations to scaffold student knowledge to what is expected of them at university. This is similar to recommendations made by Elkhindir (2020) who states that supplementary simulations in addition to problem-based learning could improve students' critical thinking on multifaceted biological processes, such as those that occur across the cell membrane. Stith (2004) further proves this point by using the example of movement through the cell membrane to explain how this process is difficult to explain with the use of static illustrations due to the membrane's dynamic nature.

Mrs. Dlamini and Mr. Zambo had prepared PowerPoint-type slides that were text-heavy and punctuated with image-only slides that contained no voice-overs. According to Crawford (2021), voice-over presentations are most effective when presenting content with visual information, which could facilitate the comprehension of the content. Therefore, this type of instruction is largely instructor-centred and is less likely to develop conceptual understanding (Elkindir, 2020), given that cellular processes happen on a scale and timeframe that is difficult to understand or see by natural means, and that students thus depend on illustrations to comprehend difficult processes (Reindl White, Johnson, Vender, Slator & McClean, 2015). Crawford (2021) states that videos are a more effective approach than static images when trying to demonstrate processes; this is something that lecturers had included in their presentations. Even though students had access to the video content and questions to answer, the presentation slides lacked student engagement with content. This could be accredited to the fact that lecturers were not prepared for the transition to a digitalized curriculum, as seen in their interview responses, showing their preference for in-person lectures as opposed to those conducted online. This could be regarded as a matter of concern, especially in light of Khosa and Mpungose's (2020) finding that an insufficient acceptance of the digitalized syllabus can compromise the value of teaching and learning.

Lecturers' preference towards in-person learning had an emphasis on engagement. In terms of constructivism, in-person engagement is important as development in knowledge acquisition is seen through social interaction. Unfortunately, the digital rift – the gap amongst individuals who have and individuals who do not have access to laptops and the internet – reduces the feasibility of interactive video conferencing for student engagement in South Africa (Mpungose, 2021). Mr. Zambo had stated, however, that he makes use of online discussion groups amongst students. This engagement is worthwhile for students as the discussion is valuable within a constructivist environment when the objective is to obtain a better theoretical understanding of numerous sides of the subject matter (Schunk, 2012).

Other than those mentioned above, one of the biggest limitations that were brought up by lecturers regarding technology use was that it prevents the development of crucial skills such as physical microscope use. If students are not exposed to the holistic experience of their field, it may impede their epistemological access (Muller, 2014). However, microscope simulation, as is used in this course, can be beneficial for students' ability to use microscopes (Kasa, 2021), especially under the current circumstances where in-person laboratory sessions have not been possible due to COVID-19 restrictions.

Learning these crucial microscope skills in an undergraduate biology course is vital, as more than 40% of students had indicated that they did not have a technological infrastructure at the high school level, which means that many students may lack the ability to prepare and view specimens using a microscope (Figure 4.1). Additionally, many students had indicated that topics such as the cytoskeleton were introduced to them at university but that they were not exposed to this content at high school. This shows that there may be gaps present in both their content knowledge and skills within this discipline that may influence their ability to accommodate new knowledge. Students who had access to technological infrastructure at school indicated in the questionnaire that their high school teachers had used the technology to enhance their visual understanding of cell biology.

The majority of students had indicated on the questionnaire that they had prior experience using technology for learning, even if it was not a part of their schools technological infrastructure. This is important as it shows that students value the use of technology in enhancing cell biology content knowledge. Students made particular mention of technology use in enhancing visualization of the content. This is backed by a large number of research studies that advocate for the importance of visual representation for an understanding of biological aspects (Climer, 2011; Kapici & Savasci-Acikalin, 2015; Reindl et al., 2015). As the results of the assessments show that misconceptions still ensued, it can be noted that previous exposure to technology may not affect student learning.

However, students' perceptions of technology can assist lecturers and curriculum advisors to use this as a resource to enhance student engagement, access, and understanding of content. Figure 4.4 shows that more students use technology for social media than for research and online learning. Where the traditional classroom may see this as a disadvantage, Mpungose (2020b) states that students' Social Media Sites (SMSs) should be seen as an opportunity for informal learning, particularly in a constructivist view, as students are accustomed to the exposure activities on these sites.

Unfortunately, the majority of students felt as though they were self-taught, which influenced their ability to understand content knowledge, as some had stated that there was an overall lack of lecturer support. This was a point also brought up by Ms. Nkosi as she had stated that it is more time-consuming to respond to personal emails as opposed to answering questions and giving explanations in a whole-class discussion.

This shows that lecturers tried to use the online platform as effectively as they could, but this was not sufficient in assisting students to overcome their misconceptions about cell biology knowledge as the final assessments had shown that many misconceptions persisted. One way that this could be addressed is the use of Technological and Pedagogical Content Knowledge (TPACK). This is vital as this framework shows that effective instruction is only achieved when all three dimensions of TPACK are successfully integrated. When looking at lecturer interviews and lecture analysis, one can see a definite lack of Technological Pedagogical Knowledge (TPK) (Table 5). As such, the potential of technology integration to bridge knowledge aps in cell biology knowledge may be limited by ineffective instruction.

This means that although all three lecturers had sufficient content knowledge and may have had good pedagogical knowledge they had difficulties in preparedness and applicability of technology to make the content accessible to students over the online platform (Table 5). This resulted in many students stating that they felt as though they were largely self-taught when engaging with the resources on the online platform (Figure 4.3). Although workshop training was available to the lecturers, preparation is essential to equip lecturers with the aptitude to improve virtual education media such as instructional videos, animations, or workshop reproductions of practical work in the direction of supplementary assistance for student understanding of content (Juanda, Shidiq & Nasrudin, 2021).

This type of media is vital in ensuring that students understand the complex dynamic nature of cell biology and histology. The effective use of technology as a means of representation during instruction is vital in cell biology, particularly to bridge the gap for students who had indicated that their high school did not have a technological infrastructure. Although the lecturers had provided students with images and videos, these were largely focused on the macroscopic aspects of the physiological processes without sufficient focus on the microscopic aspects that cannot be seen with the naked eye. This is important to note as students’ conceptions are moulded using the representations that exist founded on their daily understandings, as represented by the macroscopic images and videos, but an added emphasis on the microscopic aspects may ensure that their understanding moves towards a more scientific understanding (Niebert et al., 2013).

CHAPTER FIVE

5.1. CONCLUSION

The findings of this study indicate areas where gaps seem to exist between what learners are taught at the high school, and the prior knowledge expected of students in the first-year introductory biology course for medical students, and further study in the field. It was also noted that there are many concepts, particularly the cytoskeleton, that are not taught at the high school level, indicating insufficient prior knowledge on which to cumulatively build new knowledge. Unfortunately, there were also indications made about prior knowledge, with the introductory manual still asking students baseline questions on content that may not have been taught at high school level, as part of a revision exercise.

This study, therefore, advocates for lecturers to gain a deeper understanding of the students' foundational knowledge and to use this insight to build on the students' current knowledge structures. This could be done in a way that scaffolds between students' knowledge of cell biology from their high school knowledge and what is expected of them at university. Scaffolding could support the students by leading them through the ZPD.

Additionally, cell biology in its entirety is abstract due to the microscopic nature of cells; it is difficult for students to engage with the concept of a cell and cell organelles. It has been shown in the literature reviewed, that textbook images and superficial drawings are two-dimensional misrepresentations of the true nature of the cell and cell components and when they are represented in this way, it may lead to misconceptions. Consequently, attention needs to be given to the limitation of Technological Pedagogical Knowledge (TPK). This refers to practical awareness of hardware and software, as well as how to use technological devices to transform knowledge in such a way that it enhances understanding of the content. This is of importance as it shows that even if one has extensive content knowledge, as the lecturers in this case do, it may still be difficult to create the links between these different types of knowledge. This was demonstrated in this study as the content was online and students had access to PowerPoint presentations that had videos in them, but they felt largely self-taught, which was not sufficient, especially for the gaps in knowledge that students had. As students struggle with an inability to understand cytoskeletal and membrane structure and fluidity, lecturers could also use simulations and animations to highlight what is expected of students at the university level for them to subsequently accommodate new knowledge structures.

5.2. RECOMMENDATIONS

The CAPS documents may need to be revised for students to have a more in-depth baseline knowledge. While not all students who take Life Sciences may pursue medical sciences, expanding on the basics of cell biology, for high school and university students, may enable students to understand cellular components in more complexity. Therefore, it may be beneficial to introduce the cytoskeleton into the high school syllabus, as it may allow better understanding of the role of the cytoskeleton in relation to other topics.

Secondly, as seen through the TPACK model and the study's results, the extent to which technology is integrated and lecturers' apathy towards the use of technology in their lessons is something that needs to be addressed in science education to be efficient. Lecturers could support students through the ZPD with the use of simulations and animations.

Another recommendation would be to address the issue of access and availability of technological infrastructure. Presently, the study has shown that there may be schools that do not have a technological infrastructure. While there are issues of affordability and access, one could determine technological alternatives, such as micrographs, so that these learners are not disadvantaged.

Lastly, it may be beneficial for further studies to be conducted across subjects, faculties, and universities to see whether there is a wider issue with the difference between our secondary and tertiary education expectations as this does, as the research has shown, affect students' understanding. Longitudinal studies are also recommended to investigate the reciprocal effects of online learning and the possible development over time.

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APPENDECIES

APPENDIX A: UNIVERSITY CLEARANCE ETHICAL CLEARANCE CERTIFICATE

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Lalbahadur

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H20/05/15**
PROJECT TITLE	The effect of technology to mitigate knowledge gaps in the understanding of the cytoskeleton amongst first year medical students
INVESTIGATOR(S)	Miss L Lalbahadur
SCHOOL/DEPARTMENT	Animal, Plant and Environmental Studies/
DATE CONSIDERED	22 May 2020
DECISION OF THE COMMITTEE	Approved Risk Level: Minimal
EXPIRY DATE	07 July 2023

DATE 08 July 2020 **CHAIRPERSON** J - Knight

(Professor J Knight)

cc: Supervisor : Dr S Dukhan and Dr K Padayachee

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

Signature ______ Date 14 / 08 / 2020

RESEARCH PERMISSION LETTER – DEPUTY REGISTRAR

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

OFFICE OF THE DEPUTY REGISTRAR

30 July 2020

Letisha Lalbahadur
Student number (708147)
Master of Science
School of Animal, Plant and Environmental Studies

TO WHOM IT MAY CONCERN

"The effect of technology to mitigate knowledge gaps in the understanding of the cytoskeleton amongst first year medical students"

This letter serves to confirm that the above project has received permission to be conducted on University premises, and/or involving staff and/or students of the University as research participants. In undertaking this research, you agree to abide by all University regulations for conducting research on campus and to respect participants' rights to withdraw from participation at any time.

If you are conducting research on certain student cohorts, year groups or courses within specific Schools and within the teaching term, permission must be sought from Heads of School or individual academics.

Ethical clearance has been obtained. Protocol number: (**H20/05/15**)

Research duration: (2 Years)

RESEARCH PERMISSION LETTER– HEAD OF SCHOOL

29 April 2020

Dear Professor Pillay

Re: Request for permission to conduct research in the School of AP&ES

My name is Letisha Lalbahadur, and I am a Masters student in the School of Animal, Plant and Environmental Sciences at the University of the Witwatersrand, under the supervision of Drs Shalini Dukhan and Kershree Padayachee. I am doing research on the effect of technology to mitigate knowledge gaps in the understanding of the cytoskeleton amongst first-year medical students. Data collection for the research will be conducted between blocks two and three of the 2020 and 2021 academic years and involves analysis of how lecturers teach cytoskeletal concepts to first-year medical students. In doing so, I will be identifying any knowledge gaps from students' knowledge from school, as well as whether a technological infrastructure would assist in mitigating these gaps.

I would like to conduct the research at your School because of the service course run for medical students. These students are taught in an environment that has a technological infrastructure that I would like to investigate, and it offers me geographical convenience as well. If you allow your School to participate, my intended plan is to conduct the research in the following way over 2020 and 2021:

2020

- Tests responses comprise of the assessments that students have already completed before and after their cell biology course. Test responses of students who agree to be part of the research will be made available to me. There is one prior knowledge test, one post-test, and one assignment that makes up the set of assessments that I will analyse for participants.
- I will conduct either telephonic or online interviews; this will be done according to the lecturers' preference. I will invite three lecturers who engage with first-year medical students in this content area to participate.

2021

- Tests from the 2021 first-year medical students cohort will be analyzed in addition to those of 2020.

- Interviews with students will take place to add to the research in terms of questions that may arise while analyzing the data from 2020. I have set a framework of questions to begin with. Interviews at this point may be conducted face-to-face or on an online platform depending on the situation at this stage, and to the preference of the participants.
- Observations may be conducted to add to the research data that was collected during interviews with lecturers the previous year.

The names of all participants and School's identity will be kept anonymous and confidential at all times and in all reports, publications and presentations about the study. Pseudonyms will be used in all types of reporting on this study. Data will be kept on my laptop and any printed copies of data will be held in a locked cupboard in the postgraduate room for Science Education students at the School of Animal, Plant and Environmental Sciences. All raw data will be destroyed between 3-5 years after completion of the project. This study is for academic purposes and it will not affect any of the participants' livelihoods in any way. Research participants will not receive any incentives for participation, nor will they be disadvantaged in any way. Any participant may withdraw permission at any time without any penalty, as participation is voluntary.

If you require any further information, or for any ethics related inquiry, you can use the details listed below.

Yours sincerely,

Letisha Lalbahadur (708147@students.wits.ac.za)
Supervisors: Shalini.Dukhan@wits.ac.za; Kershree.Padayachee@wits.ac.za
Wits Human Research Ethics Committee: shaun.schoeman@wits.ac.za

Informed Consent by Professor Pillay:

Sign: ___________________

Date: ___________________

APPENDIX B: PARTICIPANT PERMISSION INFORMATION LETTER – LECTURERS (2020/2021)

Protocol Number: H20/05/15

Dear Lecturer

My name is Letisha Lalbahadur and I am a Masters student in the School of Animal, Plant and Environmental Sciences at the University of the Witwatersrand. I am doing research on the effect of technology to mitigate knowledge gaps in the understanding of the cytoskeleton amongst first year medical students. Data collection for the research will be conducted over blocks two and three of the 2020 and 2021 academic years and involves observing how lecturers teach cytoskeletal concepts to first year medical students. In doing so, I will be investigating any knowledge gaps from students' knowledge from school, as well as whether a technological infrastructure would assist in mitigating these gaps under the supervision of Drs Shalini Dukhan and Kershree Padayachee.

I have chosen your School because your School has medical students that are taught in an environment that has a technological infrastructure and offers me geographical convenience. I want to ask your permission for me to conduct my research with you in the following way over 2020 and 2021:

2020

- Please could I have access to the prior knowledge tests that students' complete at the start of your topic and any assessments that are evaluated after the cell biology and histology lectures in order to analyse how their content knowledge may have changed over the course of the semester. From my knowledge, there is one prior knowledge test, one post-test, and one assignment that makes up the set of assessments.
- I also ask that I may be able to conduct an interview of approximately twenty minutes at a time convenient for you. Due to the constraints of Covid-19, these interviews may either be telephonic or on a mutually acceptable online platform.

2021

- I ask that tests from the 2021 first year medical students' cohort will be made available in addition to those of 2020.
- I also ask to be a non-participant observer in one of your cell biology and/or histology lectures in 2021.

With your permission, I would also like to audio record the interview and the lecture for transcription purposes.

Your name, privacy and identity will be kept anonymous and confidential at all times, and in all academic writing about the study with the use of pseudonyms. This research is for academic purposes and it will not affect your livelihood in any way. All research data will be captured on my password protected laptop, and any printed documents will be kept in a locked cupboard in the Science Education postgraduate office at the School of Animal, Plant and Environmental Sciences and will be destroyed within 3 years after completion of the project. You will not be advantaged or disadvantaged in any way. Your participation is voluntary, so you can withdraw your permission at any time during this project without any penalty. Please note that as participation is voluntary, you will also receive no incentives for your participation in this study.

Please let me know if you need any further information.

Thank you.

Yours Sincerely,
Letisha Lalbahadur

Researcher: Letisha Lalbahadur (708147@students.wits.ac.za)
Supervisors: Shalini Dukhan (Shalini.Dukhan@wits.ac.za)
Kershree Padayachee (Kershree.Padayachee@wits.ac.za)
Wits Human Research Ethics Committee: shaun.schoeman@wits.ac.za

CONSENT FORM – LECTURERS (2020/2021)

Protocol Number: H20/05/15

CONSENT FORM

Title of Project: The effect of technology to mitigate knowledge gaps in the understanding of the cytoskeleton amongst first year medical students.

Name of Researcher: Letisha Lalbahadur

Please fill in and return the reply slip below indicating your willingness to be a participant in my voluntary research project.

I, ________________________ give my consent for the following:

Circle one

Permission to be interviewed

I would like to be interviewed for this study.	YES/NO
I know that I can stop the interview at any time and do not have to answer all the questions asked.	YES/NO

Permission to observe you lecturing

I agree to be observed.	YES/NO

Permission to be audiotaped

I agree to be audiotaped during the interview	YES/NO
I agree to be audiotaped during the lecture	YES/NO
I know that the audiotapes will be used for this project only	YES/NO

Informed Consent

I understand that:

- My name and information will be kept anonymous, confidential and safe, and that my name and the name of the University will not be revealed by the use of pseudonyms.
- My participation is voluntary and I will not be advantaged or disadvantaged in any way.
- I do not have to answer every question and can withdraw from the study at any time.
- I can ask not to be audiotaped.
- All the data collected during this study will be kept at the School of Animal, Plant and Environmental Sciences and will be destroyed within 3 years after completion of the project.

Sign___________________________

Date___________________________

INFORMATION LETTER – STUDENTS (2021)

Dear Student

My name is Letisha Lalbahadur and I am a Masters student in the School of Animal, Plant and Environmental Sciences at the University of the Witwatersrand. I am doing research on medical students' and lecturers' perceptions and practices of the use of technology to enhance conceptual understanding of cell biology (Protocol Number: H20/05/15). Data collection for the research involves observing how lecturers teach cell biology concepts to first-year medical students.

I am inviting you to be a part of this research for the 2021 academic year by completing a short questionnaire, which will take approximately ten minutes. Please use this Google form link https://forms.gle/PWSTwb5fBk8tk3WT9 (Links to an external site.) to complete the questionnaire.

I will not be using your own name but I will make one up, which is called a pseudonym, so that no one can identify you. In other words, all information about you will be kept confidential in all my writing about the study.

Remember, this is not a test for marks and it is voluntary. You may leave out any question that you do not wish to answer, and may choose to leave the study at any stage. I may contact you after the completion of your questionnaire for a short 10min follow-up interview which you can participate in if you would like to. This interview will take place on a mutually acceptable online platform (e.g. Microsoft Teams, Zoom, etc) which will ensure that the interview will not be overheard by anyone.

I look forward to working with you! Please feel free to contact me if you have any questions.

Yours Sincerely,
Letisha Lalbahadur

Researcher: Letisha Lalbahadur (708147@students.wits.ac.za)
Wits Human Research Ethics Committee: shaun.schoeman@wits.ac.za

CONSENT FORM – STUDENTS (2021)

An exploration of first year medical students' perceptions and practices of the use of technology to enhance conceptual understanding of cell biology.

Dear Student

Thank you for choosing to participate in my research!

By completing the questionnaire you give your consent to take part in the research.

Please feel free to contact me if you have any questions.

Yours Sincerely,
Letisha Lalbahadur
708147@students.wits.ac.za

APPENDIX C: INSTRUMENTS
INTERVIEW QUESTIONS – LECTURERS (2020)

Lecturer Pseudonym: ____

Thank you again for availing yourself for this interview. As discussed in the information letter that you received, this interview will be recorded for transcription purposes and all data will be stored at the university of Witwatersrand for three years before it is destroyed. The purpose of this interview is for me to gain insight into your thoughts and feelings of the effect of technology to mitigate knowledge gaps in the understanding of cell biology amongst first-year medical students.

Confidentially and anonymity is of utmost importance and, as such, your name will not be used in any communication, nor any write-up of the research. A pseudonym will be used in this regard, which will ensure that any answer that you give cannot be tracked back to you. I also want to reaffirm at this point again that you are aware of your right to withdraw from answering any questions at any time without risk of penalty, and as the entire process is voluntary, no incentives will be given for participation.

SECTION A: GENERAL INFORMATION

1. Which age group do you fall under?
    a. 21-30
    b. 31-40
    c. 41-50
    d. 51-60
    e. Other (Specify) _____
2. What qualifications do you hold?

    ____

3. How many years of lecturing experience do you have?
    a. 1-5
    b. 6-10
    c. 9-15
    d. 16-20
    e. Other (Specify) _____

SECTION B: OPEN-ENDED QUESTIONS

1. What are your views of technology in everyday life?

2. What support did you receive to assist you to lecture with the use of technology?

3. How comfortable do you feel using technology in whilst lecturing?

4. What kind of impact do you think that technology has on teaching and learning in general? (Follow up question – have you seen any of these impacts for yourself?)

.

5. What is your impression of the online learning resource that was available to students during the lockdown?

6. How was the experience of teaching students online different from dealing with them face-to-face?

7. Based on your experience of this online learning resource, is there anything you would do differently going forward?

8. What do you think the extent is to which cell biology knowledge is covered in high school?

9. What knowledge gaps about cell biology have you identified that students have?

10. In what ways do you think that technology can be used to address these knowledge gaps?

11. In what other ways do you feel like technology is useful in teaching cell biology concepts?

12. In what ways do you think that technology is limited in its ability to teach cell biology concepts?

QUESTIONNAIRE – STUDENTS (2021)

General Information

Description (optional)

Which age group do you fall under?

- 17-20
- 21-24
- 25-28
- 29-32
- Other...

Did you do Life Sciences at school?

- Yes
- No

Did your school have a technological infrastructure? (Software, equipment, facilities and structures)

- Yes
- No

In what year did you matriculate?

- 2020
- 2019
- 2018
- 2017
- 2016
- 2015
- Other...

Open-Ended Questions

Description (optional)

What are your views of technology in a general sense?

Long-answer text

How often do you use technology in a personal capacity?

- 1-2 hours a day
- 3-4 hours a day
- 5-6 hours a day
- 7-8 hours a day
- 9-10 hours a day
- Other...

What do you mainly use technology for? (Check all that apply)

- Research
- Record Keeping
- Internet
- Social Media
- Communication
- Other...

What are your experiences of using technology while studying, if you do this?

Long-answer text

Were there any cell biology concepts that you have/had difficulty in studying either at school or University level?

Long-answer text

What do you think made these concepts difficult to understand?

Long-answer text

In what ways did your (Life) Sciences teacher at school use technology to teach you about cell biology?

Long-answer text

What did you learn in cell biology at University that you did not know in school?

Long-answer text

What helped you the most in learning this new knowledge?

Long-answer text

What were your experiences of using online learning resources before University?

Long-answer text

Were any resources using technology provided on your University's student portal to assist your understanding of cell biology?

- Yes
- No

If yes, did you feel that these resources aided your understanding of concepts in cell biology?

- Yes
- No

Did you find that the online learning resources were guided or did you feel as if you were self-taught?

- Guided
- Self-Taught
- Other...

What do you think are the benefits of using technology to support learning in cell biology?

Long-answer text

What do you think are possible limitations of technology in learning about cell biology?

Long-answer text

OBSERVATION CHECKLIST (2021)

OBSERVATION CHECKLIST

Pseudonym: ______________________________

1. Content Knowledge

Descriptor	Poor	Moderate	Excellent	Comment
Observable mastery of content.				
Explanation of correct concepts.				

2. Pedagogical Knowledge

Descriptor	Poor	Moderate	Excellent	Comment
Observable awareness of difficult to understand concepts.				
Assists students to visualize abstract concepts.				
Use of representations				
Addressing misconceptions through pedagogical choices				
What are students engaged in?				
Are students actively or passively engaged?				

3. Technological Knowledge

Descriptor	Poor	Moderate	Excellent	Comment
Lecturers' technological comfortability.				
Suitability of technology use for cell biology.				
Student engagement during technological aspect/Student technological competency.				

4. General

Other critical moments identified: ______________________________

APPENDIX D: ASSESSMENT MEMOS
PRIOR KNOWLEDGE TEST 1

Question A

This response is dependent on the students' school experience.

Question B

This response is dependent on the students' school experience.

Question C

This is correct in part. The intermediate filaments are more permanent structures within the cytoskeletal system. The intermediate filaments, for example, form a lattice, which provides support to the nucleus. The microfilaments and microtubules can disassemble at some locations; these subunits would then be relocated to other parts of the cell where they reassemble. This plasmalemma is also supported by the microtubules. When the plasmalemma changes shape, such as when vesicles bring material into the cell (via endocytosis) or what vesicles move substances to the exterior of the cell (via exocytosis) the microtubules are involved in the change of shape of the plasmalemma in this process, this structure is therefore dynamic in nature.

Question D

The cell membrane is composed of a bilayer of phospholipids that are interspersed by proteins. The proteins are usually peripherally associated with the bilayer or traverse the bilayer. Less often, proteins are found within the bilayer. The phospholipids consist of a tail region which is hydro phobic and thus found towards the interior of the bilayer, while the head region of the phospholipid is hydrophilic and thus found in contact with the aqueous solution (i.e. the cytoplasm and the extracellular matrix). Cholesterol is an important component in maintaining the stability of the cell membrane as it acts as a buffer when there is a change in temperature.

Question E

The cell membrane restricts movement and exchange of molecules across the plasmalemma. Therefore the cell membrane is important in maintaining the internal state of the cell. The selective properties of the plasmalemma ensures that molecules required for the functioning of the cell are let in while those that are produced by the cell for export, or toxic waste, is removed from the cell to the external environment. The cell membrane also acts as a boundary layer which separates the internal content of the cell from the outside environment.

Question F

There is movement of phospholipids within the bilayer, the phospholipids can move in the lateral plane as well as flip-flop to the other side of the bilayer. The lateral movement occurs more frequently compared to the flip-flop movement required to cross over the bilayer. There are proteins that are associated with the bilayer as well. The proteins can also move within this layer. Some proteins are peripherally associated with the bilayer while others span or traverse the bilayer.

Question G

Ribosome: *Two-unit structure composed of protein, and acts as the machinery that enables the production of the amino acids chains.*

Organelle: *membrane bound structures that are found in cells, the different structures provide for different functions required in the cell for the cell to grow, divide, and survive.*

Cytoplasm: *all the content within the cell (i.e. the jelly-like fluid together with the organelles and other materials found within the cell).*

Protein: *made up of amino acid chains, which are produced by the ribosomes. These chains are usually wound into a specific shape and size, which enables the protein to function in a specific way within the cell.*

Nucleolus: *This non-membranous structure is found within the nucleus, one or more nucleoli may be present in the nucleus, and this structure disassembles prior to cell division. It is responsible for the production of ribosomal subunits.*

Cell division: *the process where the parent cell, together with its cellular components, is divided between two daughter cells.*