Exploring the TPACK of Grade 9 mathematics teachers in the Western Cape of South Africa

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I declare that this work has not been previously submitted in whole, or in part, for the award of any degree. It is my own work. Each significant contribution to, and quotation in, this dissertation from the work, or works, of other people has been attributed, and has been cited and referenced.

Signature: Signed by candidate Date: 25 October 2021

Abstract

The Department of Basic Education is striving towards improving the Grade 9 mathematics TIMSS results (Department of Basic Education, 2019). The use of technology in the mathematic classroom has shown to be able to transform mathematical education (Wiest, 2001) and, if implemented correctly in South Africa, educational technology could improve learner performance in these key areas (Western Cape Education Department, 2012). However, it appears as if South African teachers are not able to effectively integrate technology into their classrooms and professional development in this area is necessary (Saal, Graham & van Ryneveld, 2020). This Masters thesis uses a rubric based around Niess's four domains of knowledge to examine three Grade 9 Mathematics teachers' TPACK through a deep dive case study into their teaching practices during the period of COVID-19 in South African classrooms. It seeks to understand how teachers are using technology in their lessons and what areas of TPACK need to be developed within Grade 9 mathematics teachers. Evidence from this study shows that Grade 9 mathematics teachers appear to be comfortable using technology themselves in their classrooms but need guidance in learner-centred technology use. The evidence also shows that smaller classroom sizes due to COVID-19 mean that teachers appear to be more confident with the use of technology in their half-size classrooms over the sizes pre COVID-19. The results demonstrate the need for professional development aimed at learner-centred technology use, and that, in order for this usage to occur, assessment of classroom sizes needs to occur to assist in developing confidence in teachers to allow for more learner-centred use of technology in the classroom.

Acknowledgement

I wish to express my gratitude to Professor Dick Ng'ambi, my research supervisor. His guidance and critique of my work has been invaluable. I will always admire his knowledge and passion surrounding the topic of technology in education, and his dedication to aiding pre and in-service teachers with technology is inspiring.

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Chapter 1: Introduction

1.1 Background and Rationale

The history of South African and its education system means that our political history has left large educational inequities across our schools (Venkat & Spaull, 2015). South Africa's mathematics results are increasingly low with Grade 5 learners struggling to answer Grade 3 problems (Spaull & Kotze, 2015). Spaull and Venkat anaylsed South African Grade 6 mathematics teachers and found that 79% percent of them scored lower than 60% in Grade 6/7 learning materials (Venkat & Spaull, 2015). With 59% of Grade 9 learners not being able to meet the lowest TIMSS benchmark (Reddy et al., 2020), it has become imperative to improve both teacher content knowledge and learner grades.

In October 2019, the ministerial cabinet approved the 2019-2024 Medium-Term Strategic Framework for the 2030 National Development Plan (Department of Education Government Gazette, 2004). The Medium-Term Strategic Framework takes the National Development Plan and sets 5-year implementation plans with clear targets and interventions for each ministerial department (Department of Planning Monitoring and Evaluation, 2020). There are four key responsibility areas and one of these areas is of particular interest to this study.

The first key responsibility area focuses on addressing the "triple challenges of poverty, inequality and unemployment" (Western Cape Education Department, 2012) through education. Minister Motsheka has signed an agreement to improve mathematics and science results, specifically through the supply of teachers and their professional development (Department of Education Government Gazette, 2004). The document has a particular focus on raising Grade 9 TIMSS mathematics to a score of 420, which would mean that all Grade 9 learners in South Africa would be above the lowest benchmark of the TIMSS grading system. In the 2019 TIMSS results, only 41% of Grade 9 learners achieved this benchmark. Minister Motsheka is aiming for 100% of Grade 9 learners to be able to achieve this which means that improving teaching and learning in Grade 9 mathematics is of the utmost importance.

One other outcome under the first key responsibility area that the Performance Agreement covers is to improve school infrastructure so that it produces an environment conducive to teaching and learning. The Minister of Education's mandate in this key area includes using information communication technologies (ICT) to support teaching and learning (Tarling & Ng'ambi, 2016). By 2024, the Department of Basic Education wishes 90% of schools to have internet connectivity. Spaull (2011) shows that when learners have access to computers there are better learning outcomes. If implemented in a manner that promotes meaningful and effective use as per Rakes et al. (2020), access to educational technology could improve learner performances in key areas (Western Cape Education Department, 2012).

South Africa's Department of Education has developed the White Paper on e-Education policy and indicates that using Information Communication Technologies (ICT) has the potential to improve teaching and learning across the country (Department of Education Government Gazette, 2004). The department states that ICTs can help with creating access to learning opportunities, and aid in the improvement of learning and teaching (Department of Education Government Gazette, 2004). This directly fits with the 2024's Performance Agreement standards for raising mathematics learning, and implementation of ICTs in South African schools and raises a reason as to why developing TPACK amongst Grade 9 mathematics teachers would be beneficial.

Computers and technology are not the only key to improving results in learners but rather it is training teachers to integrate technology into their teaching and the curriculum (Department of Education Government Gazette, 2004) so that they are placing the technology in the hands of learners and using transformative pedagogies (Tarling & Ng'ambi, 2016). Evans and Popova (2015) showed that pedagogical interventions through the use of technology and computers have created large improvements amongst learners in developing countries. A focus on teacher training is needed to help improve the learning deficit in South Africa (Tarling & Ng'ambi, 2016) and this focus needs to be on ICT integration into Grade 9 teaching and learning if the focus is on ICT improvement in schools.

Professional development of teachers needs to be paired with the increase of access to ICT in teaching and learning (Western Cape Education Department, 2012). This means that it is important to know how teachers are integrating technology into their mathematics classrooms so that the professional development has a focus on what is needed as opposed to a one-size-fits-all style of professional development (Tarling & Ng'ambi, 2016). Teachers and learners need to be able to effectively use technologies to "access high-quality and diverse content, to create content of their own, and to communicate, collaborate and integrate ICTs into teaching and learning” (Department of Education Government Gazette, 2004). In order to improve the Grade 9 TIMSS results and the final year of schooling results, if one does not know to what extent Grade 9 Mathematics teachers are doing this already, then creating professional development programs to develop this becomes disconnected.

For technology to be successfully used in schools by Grade 9, and other, teachers in teaching and learning, the teachers and learners themselves need to be effective users (Department of Education Government Gazette, 2004). The DBE is working on transforming education through ICT technologies and plans on connecting all schools across the country to internet infrastructure (Department of Education Government Gazette, 2004). This would not lead to effective and meaningful technology use if teachers do not have TPACK . Grade 9 teachers and learners need to use this technology in the mathematics classroom to improve teaching and learning and they need to know how to use it in the curriculum (Department of Education Government Gazette, 2004).

Even with the Department of Education engaging teachers in numerous training and upskilling professional development initiatives, teachers practices seem to remain fairly unchanged and continue with the use of transmissive and lower order thinking pedagogies that do not effectively utilize technology for teaching and learning(Tarling & Ng’ambi, 2016; Rakes et al., 2020; Saal, Graham & van Ryneveld, 2020). A Grade 9 teacher with TPACK would be able to integrate their knowledge of mathematics, content and pedagogy, and technology so that there is a positive result on their learners knowledge and skills (Leendertz et al., 2013). However more than 50% of Grade 9 learners are not achieving even the lower benchmark in the TIMSS results (Reddy et al., 2020). This could mean that Grade 9 mathematics teachers are not ready or able to meaningfully integrate technology into their classrooms, showing that there is a need to focus on TPACK when it comes to teacher professional development.

This study seeks to investigate in what areas of TPACK Grade 9 mathematics teachers need to be trained in ICT use in their classrooms in order to improve the Grade 9 mathematics results. It is important for tertiary institutions and teacher professional development programmes to know this information so that these areas can be targeted.

1.2 Research questions

The Department of Basic Education is working towards improving the Grade 9 mathematics TIMSS results (Department of Basic Education, 2019). If implemented in a meaningful manner, educational technology could help to improve learner mathematics performance (Western Cape Education Department, 2012); however Saal, Graham and van Ryneveld (2020) research has shown that it seems as if South African teachers are not effectively integrating technology into their teaching and learning, with professional development of this area because of the utmost importance.

The TIMSS results show many reasons for the poor Grade 9 results, with learners' socio-economic environments being linked to their mathematics achievements (Reddy et al., 2020). The analysis of the 2019 TIMSS results show that achievements in mathematic scores are higher in more affluent fee-paying schools, with 69% of these schools recording learner access to a computer or tablet (Reddy et al., 2020). This can reinforce the findings that access to educational technologies does have a link to learner achievements (Mlachila & Moeletsi, 2019)

Because of this link between technology and achievements, one of the solutions is the use of Information Communication Technology (ICT) by teachers in the classroom as it has been shown to improve mathematics results (Tarling & Ng'ambi, 2016). The Department of Education has a drive to introduce and upgrade ICT infrastructure at schools across South Africa (Western Cape Education Department, 2012). Even though education reform has been involved in helping teachers to change their traditional style pedagogical practices to ones that are necessary for 21st century teaching and learning, it has not been sufficient and teachers continue to use technology in transmissive lower-order thinking manners (Tarling & Ng'ambi, 2016).

Even with South Africa's Department of Basic Education pushing to equip all schools and teachers with technology access and skills (Department of Education Government Gazette, 2004), South African mathematics teachers are still not effectively utilizing technology in their classrooms (Saal, Graham & van Ryneveld, 2020). Effective and meaningful technology use is when it is used in a manner that helps to improve learner conceptual understanding of mathematics and provides space for communication along with mathematical reasoning

(Rakes et al., 2020) Meaningful technology integration does not seem to be occurring in mathematics classrooms world-wide (Rakes et al., 2020), but specifically in South African classrooms where Grade 9 learners do not have a basic understanding of mathematical concepts, let alone conceptual understanding of the subject (Spaull & Kotze, 2015). This shows that teacher professional development around the effective use of technologies in classrooms is necessary.

A teacher who is effectively using technology in the classroom has what is called Technological Pedagogical Content Knowledge, or TPACK (Koehler, Mishra & Cain, 2013). It is not enough to simply equip schools and teachers with technology, but rather teachers need to be equipped with the skills, or TPACK, to drive the use forward (Thomas & Hong, 2013); and only then will we see an improvement in teaching and learning in the mathematics classrooms through technology.

The question remains as to how prepared South African Grade 9 mathematics teachers are to utilize ICTs in the classroom.

This study investigates the Technological Pedagogical Content Knowledge (TPACK) of Grade 9 mathematics teachers drawn from schools in the Western Cape through Niess's (2007) four domains of knowledge necessary for technology integration. This study explores the TPACK of Grade 9 mathematics teachers, and their integration of technology into their classrooms. It was driven by the following sub questions:

1. How developed is the TPACK of Grade 9 Mathematics teachers?
2. How should technology use change to develop TPACK?
3. How can TPACK help to develop mathematical proficiency?

1.3 Structure of the study

The structure of this study incorporates five chapters. The first chapter gives the rationale and background information, allowing for contextualizing of the study within the political and social realities of South Africa, followed by presenting the research question. Chapter two reviews the past and current literature pertaining to teacher knowledge and TPACKs influence on mathematical results amongst learners. The interconnectivity between teachers' practice of TPACK and learner mathematics results is examined, and a clear framework for measuring TPACK is defined.

Chapter three explains the research design and methodology. It describes the data collection and procedures, ethics, and validity issues. The decision to use a rubric is explained through the explanation of Niess's four domains of knowledge which are necessary for technology integration and form the conceptual framework for this study. Chapter four narrates the analysis of the data from each of the three teachers involved in the study. Each domain of knowledge is discussed according to the findings from the data.

The fifth, and final chapter presents a discussion on the findings, and limitations of the study, along with recommendations for any future studies pertaining to the subject, and concluding remarks.

Chapter 2: Literature review

This chapter gives a detailed analysis of relevant literature surrounding the research into teacher knowledge in a 21st century Grade 9 mathematics classroom. It makes a case for why developing TPACK in Grade 9 mathematics teachers is important creating mathematical proficiency, which could help to improve the Grade 9 TIMSS results in South Africa.

2.1 Mathematics deficit in South Africa

The belief that the state of South African Mathematics education is dire is widespread amongst academics, and is supported by local and international assessments (Spaull & Kotze, 2015). Researchers argue that it is important to address early-on Mathematics deficits in order to raise learners' mathematical proficiency (Spaull & Kotze, 2015). This would mean that placing an intervention in Grade 12 would be irrelevant if learners have been disadvantaged earlier on in their schooling career and are not able to 'catch-up' (Taylor et al., cited in Spaull & Kotze, 2015). This means that improving learners results in earlier grades, such as Grade 9, would be more beneficial than attempting to address the deficit in Grade 12. Grade 9 is an area of concern as it is the final year before learners decide whether or not they will take pure mathematics through to Grade 12 and need to achieve

The most recent results of the 2019 TIMSS paint a depressing picture for Mathematics at a Grade 9 level with 59% of Grade 9 learners not having basic Mathematics knowledge (Reddy et al., 2020). The below image helps us understand the 2019 TIMSS results according to the international benchmarks.

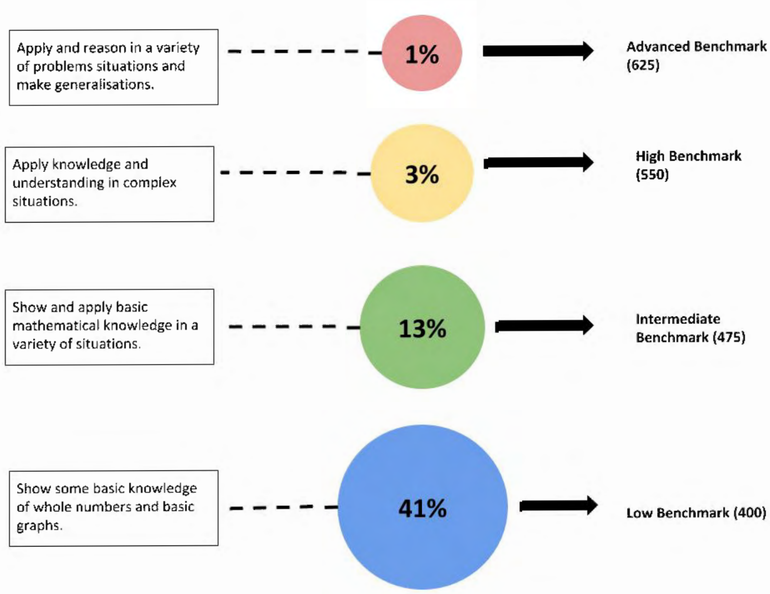

Figure 1: TIMSS benchmarks for Grade 9 Mathematics (Reddy et al., 2020)

The latest 2019 TIMSS results show a clear learning deficit amongst Grade 9 learners, which means that fewer learners are taking pure mathematics, creating tertiary enrollment deficits (Mlachila & Moeletsi, 2019). If the Department of Education intends on improving Grade 12 mathematics results, mathematics at a Grade 9 level needs to improve, and one of the ways of doing this is through classroom teaching.

The Minister of Education in South Africa, Angie Motshekga, has signed a performance agreement to raise the overall Grade 9 TIMSS score to 426 by 2023 (Department of Basic Education, 2019), meaning that it has now become important to explore ways of teaching and learning in a 21st century environment that can help to improve South African learners' mathematical knowledge. Twenty-first century teaching and learning utilizes tools that are different and enables communication in different ways (Niess, 2005). The ways that teachers may have learnt their pedagogical skill might not be using these new and different technologies available now (Niess, 2005) and so it becomes important to equip teachers with the knowledge and skills to utilize these new technologies.

2.2 Knowledge of teachers

The idea of knowledge is complicated with many facets (Shulman, 1986). In 1986, Shulman released a study that has had an impact on how teacher practice and knowledge can be assessed. He was interested in how classroom teachers use their expertise knowledge to help learners with their questions and content flaws, and in turn generate new explanations for learners (Shulman, 1986). This Content knowledge that teachers have can be divided into three different areas: subject matter (content) knowledge, pedagogical knowledge, and curricular knowledge (Shulman, 1986).

Overall, teacher performance in South Africa shows large gaps in common content knowledge (Venkat & Spaull, 2015). Spaull and Venkat based their study on Grade 6 teachers and recommended that government policy needed to focus development of Mathematics teachers on consolidating teachers understanding of the Intermediate years' content (Grades 4 and 5) in order for a foundation to be set for Grade 6 and 7 levels (Venkat & Spaull, 2015). This could be applied to Grade 9 teachers and recommend that they need to have content knowledge of prior grades in order to help improve learners' results. What is of interest is how teachers are using their content knowledge in the classroom and whether their instruction reflects this.

Spaull and Venkat (2015) report that 79% of South African Grade 6 Mathematics teachers tested lower than the Grade 6 subject content knowledge. They found that Mathematics teachers lack knowledge on common Mathematical concepts, leading to further problems with more advanced concepts, and that many teachers struggled to just do the required mathematics (Venkat & Spaull, 2015). It becomes important to define the types knowledge that Grade 9 mathematics' teachers need in order to help improve the country's mathematics results.

In 1987, Shulman looked at how these areas of knowledge intersect to create Pedagogical Content Knowledge (PCK): the intersection of subject matter knowledge and pedagogy that is unique in teachers and their profession (Shulman, 1987). PCK is the shared space between pedagogy and content knowledge (Mishra & Koehler, 2006). Grossman (1990), Park and Oliver (2008), and Helms & Stokes (2013) have all worked on Shulman's original PCK model, offering different versions of the areas of knowledge that are important for teachers to have (Fernandez, 2014). What is clear is that, regardless of the many interpretations of the original model, PCK has been considered to be the best theoretical framework available for understanding teacher skills and practice (Fernandez, 2014).

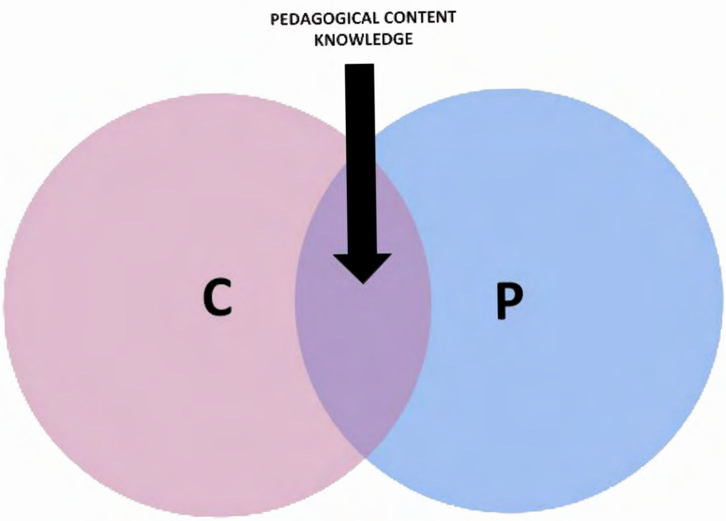

Figure 3: Shulman's intersection between subject knowledge and pedagogical knowledge (Shulman, 1986)

According to Shulman, this intersection between the two is "the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that make it comprehensible to others" (Shulman, 1986: 9). It can be argued that a teacher with PCK would know of multiple teaching strategies and methods to engage learners in the content. If one strategy did not elicit the results, the teacher would be able to explore others until learners are able to master the content. This intersection, or PCK, is what teachers need to achieve in the classroom.

2.3 Mathematical knowledge of teachers

What is considered to be successful mathematical learning has undergone several iterations during the twentieth century (Kilpatrick, Swafford & Findell, 2001). The first half of the century had a focus on knowing mathematical procedures with understanding; and, in the 1950s and 1960s, the view was that being successful in mathematics meant being able to compute extremely accurately and fast (Kilpatrick, Swafford & Findell, 2001). Currently, the thinking behind 'mathematical power' is the ability to reason, solve problems, connect mathematical ideas, and communicate these concepts to others (Kilpatrick, Swafford & Findell, 2001; Redecker & Johannessen, 2013; Awofala, 2017). This is seen quite clearly through the TIMSS benchmarks with the highest being the ability to "apply and reason in a variety of problem situations and make generalisations" (Reddy et al., 2020). This means that it becomes important for Grade 9 Mathematics teachers to be creating mathematical learners who are capable of doing this and, in turn, be successful in the learning of mathematics.

Kilpatrick, Swafford and Findell (2001) captured the term 'Mathematical profiency' (MP) to describe the desired outcomes necessary to promote in learners so that they can be successful in this subject. Mathematical Proficiency (MP) is the ability to learn Mathematics successfully (Stols et al., 2015). This is the aim of any Mathematics teacher for their learners but it is clear from the grades of South African Mathematics learners that MP is not occurring in classrooms (Ally & Christiansen, 2013).

Erlwang, in Kilpatrick, Swafford & Findell (2001), characterises Mathematical Proficiency in terms of five different strands:

- conceptual understanding—comprehension of mathematical concepts, operations, and relations
- procedural fluency—skill in carrying out procedures flexibly, accurately, efficiently, and appropriately
- strategic competence—ability to formulate, represent, and solve mathematical problems
- adaptive reasoning—capacity for logical thought, reflection, explanation, and justification
- productive disposition—habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's own efficacy. (Kilpatrick, Swafford & Findell, 2001: 116)

It is extremely important to understand that the strands are not independent, but each represents an aspect of a complex whole; the strands are entirely interwoven and it is these interlocking strands which the development of mathematical proficiency is dependent upon (Kilpatrick et al., 2001, Chapter 4).

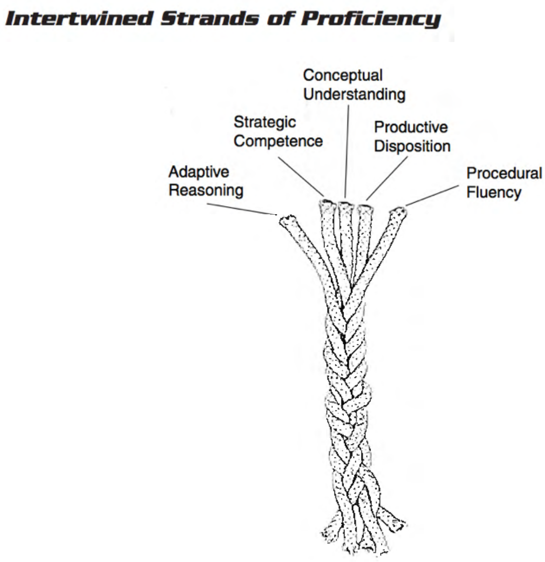

Figure 2: Kilpatrick et al.'s (2001) Strands of Mathematical Procifiency

Groves (Groves & Susie, 2012) argues that Mathematical Proficiency is what teachers need to develop in their learners. As we are living in a society that is rapidly changing due to technological innovations, learners need to be equipped with mathematical proficiency that gives them the competencies and skills that they need for work and living in the 21st century (Junpeng et al., 2019). I would argue that if a learner had developed Mathematical Proficiency, they would be able to score on the highest TIMSS benchmark – the advanced benchmark. Therefore, it becomes important that, if the South African government wants to raise its TIMMS scores, equipping teachers with the skills to create an environment capable of developing 21st century mathematical proficiency is imperative.

For a learner to have mathematical proficiency, they need to have developed the skills of all five strands. These strands are interwoven into one another and are, in ways, dependent on another (Long & Wendt, 2019). It becomes the teacher's responsibility to provide this environment and offer opportunities to develop these five strands (Ally & Christiansen, 2013).

To develop these five strands of proficiency, teachers need to have the appropriate teaching knowledge, and the domains that come with these. When it comes to developing mathematical proficiency within learners, Kilpatrick et al. (2001) also sees the three forms of knowledge that are important for teachers to have in order to teach mathematics: knowledge of mathematics, knowledge of learners, and knowledge of instructional practice (Kilpatrick et al., 2001, Chapter 10). These forms of knowledge directly link to Shulman's 1986 definition of pedagogical content knowledge, meaning that PCK is then form of knowledge that should be apparent in all Mathematics teachers; but, most importantly, a form of PCK that would create 21st century competencies and skills (Junpeng et al., 2019).

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When Shulman (1986) first made his arguments, technology was not as accessible as it is today and it was not necessary for teachers to know how to use different forms of technology in their teaching and learning. The 21st century has brought technology into the education system whereas in the 1980s this was not an issue necessary for adding into PCK. Emerging technologies in the 21st century, when utilized for transformative pedagogies, are capable of transforming classroom education (Ng'ambi, Bozalek & Gachago, 2013). These emerging technologies have the potential to build on what is important within PCK: the analogies, representations, illustrations, explanations, examples, and demonstrations (Mishra & Koehler, 2006). Teachers are able to change the way that they teach and can aid learners in making connections through traditional pedagogical tools (Mishra & Koehler, 2006). This adds a new form of knowledge necessary for teachers: Technological Knowledge (Mishra & Koehler, 2006). Because of this, it has become important for teachers to learn how to use these technologies.

Effective teaching, according to Shulman, was knowledge from domains which included ideas on how learners think and learn, and the knowledge of subject matter; however, as we move forward, a new knowledge of technology is necessary (Koehler, Mishra & Cain, 2013). New technologies can be considered to be protean (used in multiple ways) and also constantly change, with their own affordances, potentials and constraints (Koehler, Mishra & Cain, 2013). With this in mind, it is not realistic just to expect teachers to already know how to utilize these constantly changing and multiple use tools. This means that it has become necessary to add a new form of knowledge to the existing framework.

Even though Shulman's framework of PCK is still true, technologies now play an important role building on from Shulman's idea of measuring PCK, and the movement of technologies in education means that an evaluation tool needs to rather examine four main components to teacher knowledge: content, pedagogy, and technology (Harris, Koehler & Mishra, 2009). This has created a new area necessary for teachers – the Technological Pedagogical Content Knowledge (TPACK). Content, pedagogy and technology, and their relationships between these and a teacher's environment, has become the heart of good teaching (Harris, Koehler & Mishra, 2009).

If technology can help to create mathematical proficiency and the range and access to technology tools and resources for classrooms has increased (Adler & Davis, 2005), it would benefit teachers in their professional development and teacher training programs to have their TPACK developed, not just their PCK.

2.4 Defining the new knowledge framework

2.4.1 Technological Pedagogical Content Knowledge

Technology has become more accessible in schools and is being used more and more in day-to-day interactions (Niess, 2011). This means that there have been dramatic changes in most areas of human work yet education seems to have lagged behind in this (Mishra & Koehler, 2006). Mishra and Koehler (2006) argue that this is because just the technology has been looked at but not necessarily how it is used within education. The biggest issue for teachers in the 21st century is that they did not learn their 'trade' with these technologies, and do not have experience of learning with technologies; because of this, they tend not to be prepared to teach using these emerging technologies (Niess, 2011). This means that it has become important to stimulate this type of knowledge and to build it within teachers.

Because of this, Mishra and Koehler developed a framework that can be used to transform teacher education, teacher training, and teacher professional development (Mishra & Koehler, 2006): Technological Pedagogical Content Knowledge (TPACK).

TPACK is defined as “a framework for thinking about the knowledge teachers need for making instructional decisions with respect to integrating digital technologies as learning tools” (Niess, 2011). It is a dynamic framework which examines the knowledge teachers need in order to design and develop both their curriculum and their form of instruction and help to guide learners’ ability to think and learn with digital technologies (Niess, 2011).

TPACK is made up of seven different knowledge areas as shown in the Figure 4. Each of these knowledge domains is of importance, but it is where they intersect that this research is interested in, and is the very area that teacher training and professional development needs to focus on and make sure is fully developed within teachers so that they are capable of creating mathematical proficiency in their Grade 9 learners in a 21st century classroom.

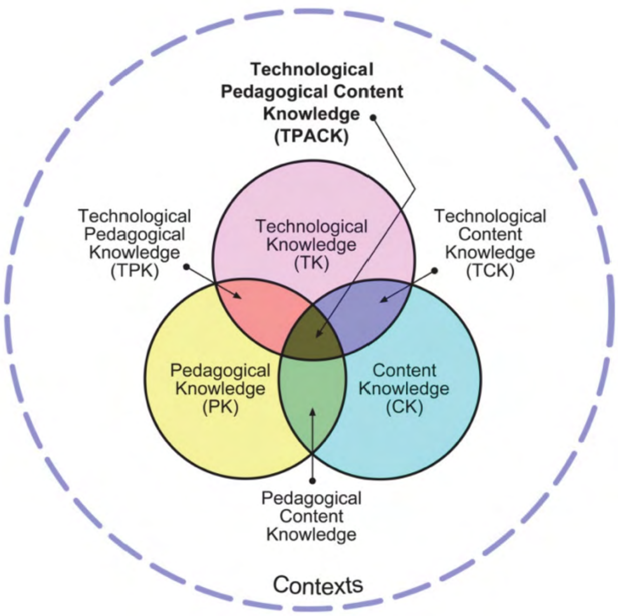

Figure 4: Mishra and Koehler’s TPACK framework (Mishra & Koehler, 2006)

The first area of knowledge that this framework of TPACK considers is a teacher’s content knowledge (CK) which is their knowledge encompassing the subject matter that needs to be covered in the classroom by both the teacher and then learners (Koehler, Mishra & Cain, 2013). It is necessary for a teacher to be able to differentiate between the content knowledge for a Grade 9 Mathematics classroom in comparison to a first year of a Mathematics degree in a university. Teachers need to understand the “deeper knowledge fundamentals of the disciplines in which they teach” (Koehler, Mishra & Cain, 2013: 63), which would mean that a Grade 9 Mathematics teacher would need to know the concepts, theories, and frameworks related to their subject. A teacher without this CK knowledge may mean that learners are delivered incorrect information, which would conclude in subject misconceptions, meaning this knowledge is extremely important to have.

Pedagogical knowledge (PK) is a teacher's knowledge about the methods and practices of teaching and learning that occurs in the classroom (Koehler, Mishra & Cain, 2013). This form of knowledge encompasses a teacher's ability to understand how learners learn, classroom management, knowledge on lesson planning and how best to assess learners (Koehler, Mishra & Cain, 2013). A teacher with pedagogical knowledge will know techniques and teaching methods to use in their classroom, because they have a strong understanding of how learners acquire knowledge and skills. PK involves knowledge of "cognitive, social and development theories of learning" (Koehler, Mishra & Cain, 2013: 64) and can apply this to the learners in the classroom.

Pedagogical Content Knowledge (PCK) remains consistent with Shulman's definition and how pedagogy is applied to specific teaching content. Shulman looks at how PCK is when a teacher is capable of interpreting the subject matter, discovers different ways of representing it, and then is able to structure the material to multiple conceptions and the learners' prior knowledge (Shulman, 1986). This means that PCK is the "core business of teaching, learning, curriculum, assessment, and reporting" (Koehler, Mishra & Cain, 2013: 15), and is essential for one to be an effective teacher.

One of the new forms of knowledge domains is Technology Knowledge (TK). It is extremely difficult to define the concept of TK as technology is in a constant state of change (Koehler, Mishra & Cain, 2013). Koehler, Mishra, and Cain have chosen to link the definition of technology in the TPACK framework to that of Fluency of Information Technology (FITness) which was defined by the Committee of Information Technology Literacy of the National Research Council in 1999 (Koehler, Mishra & Cain, 2013). This definition of FITness lays out technology knowledge as a deep understanding where the person is able to use technology capably in both their everyday lives and at work; they are capable of recognizing when technology can aid a task, and when not to use it, meaning that technology understanding goes deeper into problem solving instead of just general computer literacy (Koehler, Mishra & Cain, 2013). It is important to note that this form of knowledge is constantly developing and evolving within a person due to the ever-changing forms of technology available.

Technology has been changing people's content knowledge throughout history. Technology has aided in scientific findings and innovated many professions throughout the centuries. It becomes very important for teachers to understand the impact that technology can have on their teaching subject in order to make sure that the correct technology tools are being chosen (Koehler, Mishra & Cain, 2013). When a teacher is able to understand how technology and content are able to influence and also constrain one another, a teacher has Technological Content Knowledge (TCK) (Koehler, Mishra & Cain, 2013).

Technological Pedagogical Knowledge follows a similar vein to TCK but instead of how the technology fits the content, the teacher needs to understand how teaching and learning in the classroom can change depending on the technology used (Koehler, Mishra & Cain, 2013). A teacher with TCK can analyse the affordances and the constraints of a particular tool as they design their pedagogy and classroom strategies (Koehler, Mishra & Cain, 2013). For example, a teacher with PCK would be able to look at a cellphone and see multiple uses for it as a teaching strategy, or know when not to use it because it cannot achieve the task necessary. As most technologies are not necessarily designed for educational purposes, it becomes extremely important for a teacher to have developed PCK so that they can best see how to use these tools in their classrooms (Koehler, Mishra & Cain, 2013).

When all of these knowledge areas intersect, you have Technological Pedagogical Content Knowledge (TPACK). TPACK is "a understanding that emerges from interactions among content, pedagogy, and technology knowledge" (Koehler, Mishra & Cain, 2013: 16). The TPACK framework helps to think about the knowledge that all teachers would need to make decisions about the integration of technology into their classrooms as learning tools (Niess, 2011). In today's world, it is becoming increasingly important for teachers to be able to utilize TPACK as a strategy to think when planning and preparing lessons for learners to explore their subject with the use of technology (Niess, 2011).

TPACK is the basis of effective teaching with technology (Koehler, Mishra & Cain, 2013). It allows a teacher to take their knowledge of content and pedagogy and include emerging technologies to aid their learners in mastering the subject (Brantley-Dias & Ertmer, 2013). It is important to note that technology is not the main aim with TPACK and that pedagogy and content play just a large a role with technology being another form of knowledge (Brantley-Dias & Ertmer, 2013).

2.4.2 Critiques of TPACK

There have been critiques on the development of TPACK as a framework. Brantley-Dias and Ertmer (2013) argue that, if one looks closely at Shuman's study on teacher knowledge, one can see that a new form of knowledge was not necessary to integrate as it was already there. Shulman (1986) referred to curricular content knowledge and described instructional tools and materials that were useful for teaching. They argue that whilst technology was not mentioned, other technologies such as film, software, and visual materials were, and that if Shulman had written his article a few years later, computer technologies would have been included (Brantley-Dias & Ertmer, 2013). Teachers would have needed to understand how these types of tools would have helped to teach the different forms of content – a clear example of how TPACK is used.

A recent review of literature focusing on TPACK questions as to whether the model of TPACK is helping to develop this form of knowledge. Saubern, Henderson, Heinrich, and Redmond (2020) found that studies have shifted from investigating the specialist form TPACK knowledge to analyzing the separate seven domains of knowledge. They found that researchers are rather investigating these domains and comparing them to one another, and that the central idea of teachers developing a specialized form of knowledge from technology to TPACK has fallen away (Saubern et al., 2020). This means that research has not been focused on the core idea of teachers integrating technology into content and pedagogy, and rather has had a focus on the domains as if they are the objects of the study (Saubern et al., 2020). This means that for future studies it becomes important to make sure that the focus is on TPACK and not a separate analysis of each of the knowledge domains.

There is a question of whether the actual diagram used to represent TPACK is what is causing this disconnect in analyzing TPACK. Mishra and Koehler struggled to find a way of representing the relationship between content, pedagogy, and technology, and went through many iterations during their design process (Warr, Mishra & Scragg, 2020). Saubern, Henderson, Heinrich, and Redmond (2020) argue that if Mishra and Koehler had chosen a different diagram to represent TPACK, or perhaps no diagram at all, researchers may have been able to concentrate more fully on TPACK and not be distracted by the complexities of the other domains of knowledge. This study needed to make sure that the data analysed focused on analyzing the intersections of technology, content, and pedagogy, and not be distracted by the visual representation of other domains of knowledge.

Another argument is that TPACK needs to include another 21st century skill which is necessary for education: computational thinking. Computational thinking is a problem-solving skill of analytical thinking (Mouza et al., 2017). Mouza, Yang, Pan, Ozden, and Pollock (2017) suggest that any further development on TPACK needs to integrate computational thinking as this can assist teachers and learners to move from being consumers to creators of technological and computing innovations. This concept of learners being active creators of content through technology is of interest in this study when it comes to TPACK and mathematical proficiency.

Mishra himself sees a need to make minor changes to the TPACK framework. The most known diagram includes a dotted circle around it that is labeled as 'context'. This circle of context encloses a space but there is no form of knowledge linked to it. Mishra (2019) suggests a solution where this outer dotted circle is renamed as Contextual Knowledge. This knowledge encompasses not only the teacher's knowledge of what technologies are available, but their understanding of their school's situation, the province, and even the country's national policies (Mishra, 2019). Without understanding and knowing their own context, the effectiveness and success of TPACK can be limited.

Mishra (2019) suggests that the new knowledge domain's acronym should be ConteXtual Knowledge, calling it XK. The X can show a variable, and this is important as contextual knowledge is variable, changing from school to school, city to city, and teacher to teacher (Mishra, 2019). XK highlights the constraints that a teacher may have when it comes to TPACK in terms of the situational and organizational contexts that they work within (Mishra, 2019). It becomes not just how technology, pedagogy, and content overlap, but in knowing how the school functions, and the effects these contexts have on TPACK.

One thing does become clear: for a study to truly research TPACK in teachers, there needs to be only one purpose: to understand how teachers are using technology for teaching and learning (Saubern et al., 2020); but also to consider the context that the teacher is doing this within. This concept of using TPACK to shift learners from being consumers of knowledge in the classroom to creators of content is a very important area of meaningful technology use and TPACK. Tarling and Ng'ambi (2016) created the Teacher Change Frame to map teachers' pedagogical changes from transmissive pedagogies to transformative pedagogies with the use of technologies. Transformative pedagogies were defined as pedagogies that involved learners evaluating and creating (Tarling & Ng'ambi, 2016) and they argued that technology can be used by teachers in the classroom in either a Quadrant D manner where the usage is teacher-centred with lower-order thinking skills; or Quadrant C where the usage is learner-centred with a focus on higher-order transformative pedagogies (Tarling & Ng'ambi, 2016). In order for teachers to develop the higher order thinking of mathematical proficiency in their Grade 9s, this study argues that technology needs to be used in a manner that is in Quadrant C, and that a teacher who is able to use technology in this manner would have developed TPACK.

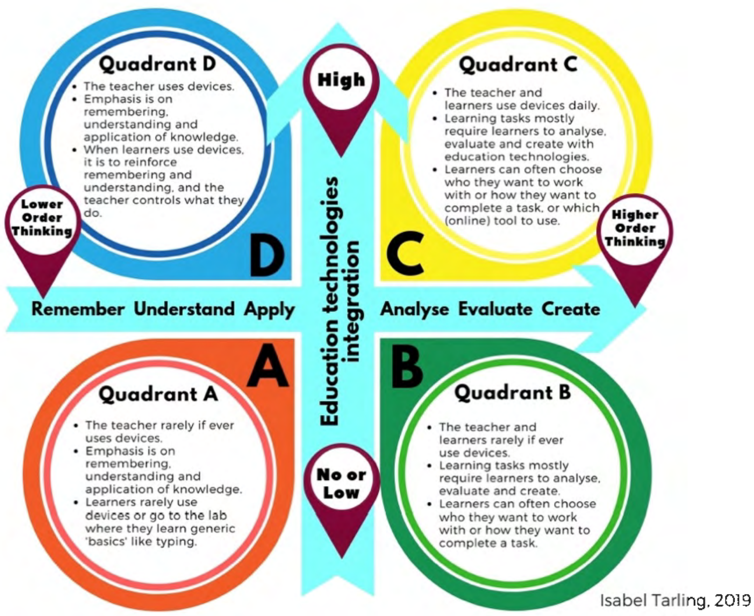

Figure 5: The Teacher Change Frame (Tarling, 2019)

Internationally, researchers are using TPACK as the framework to design and develop teacher training programs as it allows to equip pre-service teachers with interconnected knowledge (Baran, Chuang & Thompson, 2011). If this were so, it would mean that current in-service teachers need to have TPACK evident in their teaching; and, if they do not, then a focus on TPACK in teacher professional development needs to be happening.

2.4.3 Understanding technology in mathematics education through TPACK

Technology can help to facilitate mathematics learning as long as it is not being used as a form of instruction (Wiest, 2001) and so teachers need to shift into transformative pedagogies of Tarling and Ng'ambi's Quadrant C (Tarling & Ng'ambi, 2016) with learner exploration and creation. Transformative pedagogies with technology involve redefining classroom learning and teaching so that the use of technology by both teacher and learner means that what is happening could never occurred in a previous classroom (Kihoza et al., 2016; Tunjera & Chigona, 2020a).

Pairing the TPACK framework with another framework, such as the substitution, augmentation, modification, redefinition (SAMR) model, helps to show how a teacher with developed TPACK is using transformative pedagogies to completely redefine the teaching and learning occurring in the classroom. The SAMR model helps to plot a process that a teacher goes through when adopting a technology in their classroom pedagogy (Tunjera & Chigona, 2020a). Once a teacher is using the technology in a transformative pedagogical manner, they have TPACKed and are using technology in a learner-centred, constructivist manner (Tunjera & Chigona, 2020a) – Quadrant C of the Teacher Change Frame (Tarling & Ng'ambi, 2016).

Figure 6: The TPACK SAMR Model (SAMR reference) (Tunjera & Chigona, 2020a)

In order for this integration of technology into mathematics to be transformative, teachers need to know how that type of technology can fit into the curriculum (Wiest, 2001) and creating a learner-centred environment that redefines the classroom (Tunjera & Chigona, 2020a). In mathematics, learners need to be able to take an abstract concept and see it as a concrete one (Stapf & Martin, 2019) and technology can be specifically useful in the mathematics classroom to guide learners and help them engage in abstract mathematics contexts (Taleb, Ahmadi & Musavi, 2015). The technology can help make abstract concepts concrete and also facilitate the configuration of this in the learners' minds (Stapf & Martin, 2019). For example, when learners can use computers simulations to build scenarios, the connection to the mathematical concepts can be deeper than a traditional classroom setting (Taleb, Ahmadi & Musavi, 2015). Without TPACK, teachers may struggle to engage in meaningful integration, aiding the abstract to the concrete.

The Department of Basic Education desires for all Grade 9 learners in South Africa to be able to achieve the TIMSS low benchmark and have basic mathematical knowledge (Bate, Day & Macnish, 2013). Research has demonstrated that gaming technology placed in the hands of the learners can help with basic mathematical skills and knowledge (Department of Basic Education, 2019). Shin, Sutherland, Norris, and Soloway (2012) developed a Nintendo game for learners to play that taught basic arithmetic skills and tested the results in comparison to a group of learners using paper-based flash cards. The results showed that over a 5-week period the learners who used the Nintendo game improved their results by 11% versus the paper-based group who only raised their results by 4%. The gaming technology was able to improve the learners' basic arithmetic levels regards of the level that they were at (Shin et al., 2012) and using technology in this manner could be beneficial for South African Grade 9 learners to move past the low benchmark in the TIMSS results.

Sincuba and John (2017) found that when innovative graphing technology tools were used in rural disadvantaged South African classrooms, 92% of the Grade 10 learners in the study found that the software was beneficial in improving their mathematics skills. The use of the graphing technology tools by the learners made them want to engage more with the mathematics (Sincuba & John, 2017). For this learner-centred Quadrant C learning to be implemented, teachers need to be educated on how to effectively integrate the technology (Sincuba & John, 2017), which would involve developing their TPACK.

Mobile, or m-technologies, can help support the transition between the Grade 9 and 10 mathematics classrooms. M-technologies can be defined as hand-held devices with wireless access (Taleb, Ahmadi & Musavi, 2015). Roberts and Vänskä (2011) explored how interactive learning materials accessible on mobile technology used by learners could benefit mathematics learning. They found that even though there was an overall drop in grades for the learners in the study, there was less of a drop for those learners who engage with the mobile learning service (Roberts & Vänskä, 2011). They hypothesize that the technology available on mobile devices can dampen the trend of declining mathematics grades for learners as they move from Grade 9 to 10 (Roberts et al., 2015). Their study speculates that this technology access gives learners more examples and work, and the immediate feedback is helpful to learners to develop procedural fluency and problem solving (Roberts et al., 2015). If this is true, technology could help South African Grade 9 learners move towards the advanced TIMSS benchmark so developing their TPACK becomes an imperative.

A 2020 study found that there is insufficient evidence to support claims about technology's effectiveness to support mathematical learning outcomes(Rakes et al., 2020). The study analysed 1476 mathematics educational technology papers, but after careful examination by coders, 100 papers were used with the others excluded for reasons such as no control groups, no achievement data, no technology integration, not based on mathematics, not in English, and further reasons (Rakes et al., 2020). Most of the studies examined seemed to only measure the learners' achievement through their procedural skills, and Rakes et al. (2020) strongly urge other studies to include conceptual understanding. Technology offers exploratory opportunities for learning and aids learners in building connections, but studies in mathematics educational technology do not seem to move past skills-based outcomes (Rakes et al., 2020). Conceptual understanding can help learners take their fact and recall and apply it to new situations, and this would help Grade 9 learners move past the TIMSS Intermediate benchmark so it is important that South African future studies focus on technology and pedagogy use through conceptual understanding.

Even when mathematics teachers believe that technologies can aid in developing problem-solving abilities in learners, this does not mean that the teachers are capable of effectively integrating the technology. Saal, Graham, and Rynveld (2020) found that teachers from the South African schools that they sampled were not meaningfully integrating technology. The teachers believed that technology could help develop problem solving abilities in their learners but that the teachers were mostly using YouTube to reinforce concepts or substitute for their teaching (Saal, Graham & van Ryneveld, 2020). This form of use would be in Quadrant D, and until the technology is transformative and in the hands of the learners, it will not lead to meaningful or effective teaching (Kihoza et al., 2016; Tarling & Ng'ambi, 2016; Rakes et al., 2020; Tunjera & Chigona, 2020). It can be argued that teachers with fully developed TPACK would help to make sure that the technology is being used to develop problem solving, and also that it is used more naturally in the classroom.

A mathematics teacher with underdeveloped TPACK would not use technology in a transformative and learner-centred manner (Tunjera & Chigona, 2020a). This can be seen in how South African teachers have access to the internet but they seem to be holding back from using which resources are online to help improve their teaching (Taleb, Ahmadi & Musavi, 2015). Stols et al. (2015) found that South African mathematics teachers had a positive reaction to the idea of technology use in their classrooms but that they found the technology overwhelming. They agreed that technology could benefit teaching and learning in their mathematics classrooms but felt that their computer and software knowledge was insufficient to truly embrace technologies and new pedagogies (Stols et al., 2015). If the focus was on developing these teachers' TPACK, they may possibly find integrating technologies more favourable in their classrooms.

It becomes clear that the key defining factor in whether technologies are used in a transformative manner in the classroom is the teacher (Thomas & Hong, 2013). Because of this, it is important to pay careful attention to the affordances of the teacher's environment, and their attitudes towards the technology (Thomas & Hong, 2013). Even if a teacher has TPACK, they may still struggle to integrate depending on the constraints and affordances of their particular environment (Thomas & Hong, 2013). This is why when exploring mathematic teachers' TPACK, it is important to also pay attention to their ConteXtual Knowledge (XK) as then constraints within this knowledge could be a reason why it seems as if they are not integrating technology but this does not necessarily mean that they do not have TPACK (Mishra, 2019).

2.4.4 Knowledge domains of TPACK

TPACK involves multiple domains of knowledge (Hofer & Grandgenett, 2012). Niess (2005) adapted Grossman's 1989 and 1990 domains of knowledge within PCK to include the use of technology in order to describe what outcomes are necessary for developing TPACK (Niess, 2005). She argues that mathematics teachers need to be guided towards developing their knowledge and thinking so that there is an "overarching conception of teaching with technology" (Niess, 2005: 511).

These domains of knowledge are as follows:

1. Knowledge of an overarching conception about the purposes for incorporating technology in teaching mathematics
2. Knowledge of students' understandings, thinking, and learning of mathematics with technology
3. Knowledge of curriculum and curriculum materials that integrate technology in learning and teaching mathematics
4. Knowledge of instructional strategies and representations for teaching and learning mathematics with technology (Niess et al., 2009: 8)

The above domains of knowledge need to be investigated if analyzing Grade 9 mathematics teachers' TPACK.

2.5 Measuring TPACK

It is difficult to measure TPACK (Mishra & Koehler, 2006). This is because a teacher does not immediately go from not having TPACK to having fully developed TPACK but rather goes on a non linear journey towards TPACK (Niess, van Zee & Gillow-Wiles, 2010; Tarling & Ng'ambi, 2016; Tunjera & Chigona, 2020a). Niess, Sadri, and Lee (2007) adapted Everett Rogers' (1995) model of the innovation-decision process and developed a model of five levels that show teachers' development as they learn to integrate technologies. Niess, Sadri, and Lee argue that, as they observed Mathematics teachers over a 4-year period learn to integrate new technologies into their teaching and learning, they found that the teachers progressed through different levels in their journey of learning (Niess et al., 2009). These five levels are:

1. Recognizing
2. Accepting
3. Adapting
4. Exploring

5. Advancing (Niess, van Zee & Gillow-Wiles, 2010)

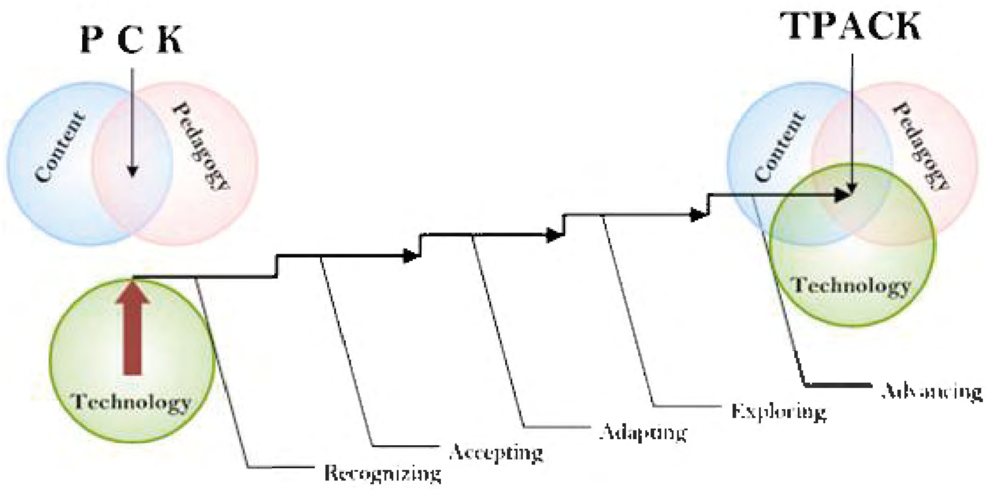

Figure 7: Visual description of teacher levels as their thinking and understanding merge toward the interconnected and integrated manner identified by TPACK (Niess et al., 2009).

Figure 7 shows how a teacher can move through the levels and merge the knowledge domains of technolgy, content, and pedagogy. What is important to note is that a teacher might not shift their practice in a consistent pattern across the levels, and that whilst a teacher may increase in disposition with technology in one mathematical topic, they could change levels when using a different type of technology (Niess et al., 2009). Using these levels to measure TPACK would ensure that the researcher is not distracted by the other domains of knowledge and focuses solely on measuring how developed a mathematics teacher TPACK really is (Saubern et al., 2020).

Harris, Grandgenett, and Hofner (2010) report that there are three different types of data that researchers can use to assess teacher TPACK: self-reporting, observed behavior, and teaching artifacts. Kaplon-Schilis and Lyublinskaya (2020) confirm this and break it further down into teaching artifact analysis, interviews, self-assessment surveys, classroom observations, and questionnaires. Amongst these forms of data, using self-assessment, such as a questionnaire, can lower the validity of the results as teacher perception of their own TPACK often differs from the reality (Kaplon-Schilis & Lyublinskaya, 2020). A teacher can think that they are using technology in a way that encompasses both pedagogy and content, but the reality may be very different. Because of this, the area of self-reporting for this study would rather focus on interviews with teachers where structured questions can help to get to the heart of their TPACK.

Teacher knowledge is most directly shown through their actions, artifacts, and their own statements, instead of being directly observable so it is necessary to use assessments which show teachers' TPACK in reliable and valid ways (Kaplon-Schilis & Lyublinskaya, 2020). Considering how difficult it is to raise multiple types of data for numerous teachers, Harris, Grandgenet, and Hofner (2010) advice using lesson instructional plan teaching artifacts as these show teacher decisions but also give a view into their pedagogical reasoning (Harris, Grandgenett & Hofer, 2010). They put forward that measuring a teacher's TPACK by direct classroom observation is not possible as one also needs to see the decision process that led to those actions (Harris, Grandgenett & Hofer, 2010). Once that has been done, a teacher's actions in the classroom can truly be discerned. This means that a researcher would need to examine both the teacher's classroom lesson, and also their lesson plans, artifacts used whilst teaching, and engage in conversation with them to truly understand how developed their TPACK is.

Harris et al. (2010) adapted Britten and Cassady's (2005) Technology Integration Assessment Instrument (TIA) to measure technological pedagogical knowledge (TPK), technological content knowledge (TCK), and technological pedagogical content knowledge (TPACK) (Harris, Grandgenett & Hofer, 2010). They did not measure individual areas of content knowledge, pedagogy, or technology, as they wished to focus solely on technology integration. They developed a rubric to evaluate pre-service teachers however Harris et al. believe that the rubric would provide similar results for in-service teachers (Harris, Grandgenett & Hofer, 2010). Whilst the criterion for measuring TPACK has gone through validity testing, it does not focus on Niess' domains of knowledge or the 5-stages of innovation, which are of particular interest in this study.

In 2012, Hofner and Grandgenett focused on a three-semester course targeted towards students who have a degree in a discipline and are entering a teacher preparation course. Their measurement collected data at four key points throughout the course and involved surveys, reflections, observations, and interviews. Their aim was so see how pre-service teachers develop their TPACK and whether it was evident within their lesson planning

(Harris, Grandgenett & Hofer, 2010). Their data showed that technology preparation needs to be integrated throughout the teacher programme (Hofer & Grandgenett, 2012). This study is of interest as it combined data gathering of both lesson observation and lesson plan analysis. This was done for the researcher to see if teachers diverged from their planned lesson at all, which would affect the analysis of TPACK. It is clear that when analyzing Grade 9 Mathematics teachers, it may be necessary to both observe lessons and also look at lesson plan artifacts from teachers and learners to see the entire picture.

Patahuddin, Lowrie, and Dalgarno (2016) used the TPACK framework to examine critical instructional events and discover the knowledge that mathematics teachers needed to aid students and their learning in classrooms with technology. Critical events were defined as incidents in the classroom where a misconception or incorrect conjecture was developed due to student learning (Hofer & Harris, 2012: 33–34)). They recorded a single teacher's lesson as a case study and analysed the critical events in her lesson. The findings showed that the teacher struggled in the three main areas of technological content knowledge, technological pedagogical knowledge, and pedagogical content knowledge. This meant that her TPACK was not developed as TPACK relies on the intersection of these quadrants (Patahuddin, Lowrie & Dalgarno, 2016). Their study shows that using a TPACK framework to analyse mathematical teaching can aid in creating a deep understanding of the issues surrounding technology integration (Patahuddin, Lowrie & Dalgarno, 2016) which is so very necessary in South African mathematics classrooms.

Lyublinskaya and Tournaki (2011) developed a TPACK levels rubric which combines the five innovation levels defined by Niess et al. (2009) with Niess's multiple domains of TPACK knowledge. Teachers are assessed on their practice and their TPACK level is their lowest score across the four components (Lyublinskaya & Tournaki, 2011). What makes this rubric useful for this study is that the technology integration is measured in each domain in both of the teachers use technology and how the learners use the technology. This is important to acknowledge as technology usage needs to be transformative and learner-centred to create meaningful technology use (Ng'Ambi, 2013; Ng'ambi et al., 2016; Tarling & Ng'ambi, 2016).

This TPACK Levels Rubric has been used in multiple studies for pre-service teachers (Lyublinskaya & Tournaki, 2011) and has shown that independently developing teacher TK, PK, and CK does not increase TPACK (Lyublinskaya & Tournaki, 2011; Kaplon-Schilis & Lyublinskaya, 2020). The conclusion here is that teacher education programs must focus on developing TPACK along with the other areas to aid teachers in effectively using technology in their teaching (Kaplon-Schilis & Lyublinskaya, 2020).

This rubric developed by Lyublinskaya and Tournaki is useful to measure TPACK as it specifically looks at each of the domains of knowledge necessary for teacher knowledge of integrating technology into the teaching and learning of mathematics, and leaves room to measure the journey that a teaching takes when adopting new technologies into their teaching and learning (Niess et al., 2009). It also examines both how teachers use technology and how learners use technology

This rubric has been developed to assess lesson plans, lesson artifacts, and observed behaviours, such as lesson observations (Lyublinskaya & Tournaki, 2011). This makes it an appropriate tool to use to assess Grade 9 mathematics teachers' TPACK as the focus is on the development of TPACK with no distractions of other domains of knowledge. It also allows for assessing multiple resources, which will give a more rounded view of a teacher's TPACK instead of their personal opinion on their technology integration, and also be able to take into account their ConteXtual Knowledge (XK).

In conclusion …

This chapter has explored the concept of mathematical proficiency and the types of knowledge that is necessary for teachers to have to develop this. It has investigated how the use of technology can help to improve mathematics teaching and learning in classrooms, and provided a framework to use when analysing TPACK as a form of teacher knowledge. The following chapter introduces the research methodology.

Chapter 3: Research methodology

The focus of this chapter is to investigate Grade 9 Mathematics teachers' TPACK in the Western Cape. An interpretive research methodology has been employed to collect and analyse the data as it relies on both a rubric and qualitative interview questions (Creswell et al., 2006). The researcher currently works in teacher training and this influenced the decision to use an interpretive study due to her experience in order to explore this area instead of rigorous measurement to test a hypothesis (Noor, 2008).

3.1 Overview of the study

The overall design of this study is qualitative. Qualitative research can be defined as one that can draw on one or more of three different methods for gathering data (Lodge, 2006). This research involves clear qualitative as the researcher seeks to understand the participants in their own terms and the participants' unique social environment (Lodge, 2006). The lens that the researcher has used is an interpretive one. An interpretive study tends to be qualitative and involves understanding the participants of a study under their own terms, and in their own unique social environment (Howe, 2004). Using an interpretive framework in the approach can help to "empower the participants, recognize their silenced voices, honour their individual differences, and position both the researcher's and the participant's views in a historical / personal / political context" (Creswell et al., 2006: 5).

3.2 Selecting schools and participants

The teachers selected for this study all work at Western Cape government schools. In order to discover if the same levels of TPACK need to be developed amongst Grade 9 Mathematics teachers, the schools varied. The researcher met with the Western Cape Education Department (WCED) for assistance in finding participants for the study. The mathematics curriculum head for the WCED put the researcher in contact with curriculum advisors in the province. From the responses, three schools were selected based on quintiles. The National Norms and Standards for School Funding in South Africa classifies schools into wealth quintiles (Mestry & Ndhlovu, 2014). The poverty score of each school relates to a quintile rating for the school with 5 being the ones with the most wealth and 1 being the ones in the poorest of areas (Mestry & Ndhlovu, 2014). This study wanted to select schools in quintiles 3, 4, and 5 to have a variance of mathematics teachers as part of the case study; however, due to a struggle to gain access to schools during COVID-19 protocols, only Quintile 3 and 5 schools were accessible. The teachers in the schools were the only Grade 9 mathematics teachers at the schools.

School A is listed as a Quintile 5 school with a learner body of 1400 and a teaching staff of 27. During COVID-19 in 2020, only half of the learner body was able to be at school at one time, meaning that classrooms have been reduced from 41 learners down to 22 learners. Even though School A has been listed as a Quintile 5 school, meaning that it receives the least amount of funding from the Department of Basic Education (Mestry & Ndhlovu, 2014), it is situated in a less affluent part of town, with learners coming from poorer areas.

School B is located in the more leafy-green affluent suburban areas of town. It is listed as a Quintile 5 school. The school is relatively new, being built in the last 9 years and has 479 learners and a staff of 27 teachers. It is the only school out of the four where all learners have to take the subject Mathematics through to Grade 12. The learner classroom size is usually 30 learners but In COVID-19, this as been reduced down to 15 learners on alternative days. The school runs from Grade 8 through to Grade 12 and attracts learners who commute from poorer areas as well as learners from middle-class backgrounds in the surrounding suburbs.

School C is a Quintile 3 school also located in the lesser affluent area of town. This school has a teaching body of 36 teachers and 1563 learners. School C is a primary school, and has classes from Grade R through to Grade 9. The school has requested funding for more teachers, however the Department of Education will not provide the funding for any more. The learners attending the school are from an extremely poor background and mainly live in the area. COVID-19 means that the classroom sizes at School C have also been reduced with a new size of 20 learners on alternate days instead of the normal 41 learners.

The schools selected needed to fit certain criterion:

- The teacher needed to have access to a computer in the classroom or the computer lab
- The computer or computer lab needed to have access to internet connectivity

Because of this, the selected schools could not be from very impoverished areas, usually Quintile 1 and 2 (Roberts & Vänskä, 2011).

This study chose to select two in-service teachers and one pre-service teacher who was on the brink of graduation with a Post Graduate Certificate in Education. Because it is important that teachers are able to appropriate technology in teaching and learning (Tunjera & Chigona, 2020b), the comparison between in-service and newly qualified teachers will help to not only recommend the findings to teacher professional development programs but also initial teacher training.

The schools and teachers chosen were located within an urban area in the Western Cape. As this study took place during 2020, COVID-19 posed a problem of gaining access to schools. Teachers and Grade 9 learners only returned to the classroom in the last quarter of the year but schools restricted visitors due to the Department of Basic Education's COVID-19 regulations (Department of Education, 2020). As many schools were conducting remote emergency teaching, it seemed as if there was a fear that this research could be critiquing their use of online learning in the COVID-19 sphere, which meant that access to schools became even harder.

3.3 Methodology

The methodology chosen was a multiple case study. Case studies allow for rigorous exploration of a phenomenon in context (Baxter & Jack, 2008). A case study allowed for a greater depth of understanding of the TPACK of the mathematics teachers and to see where potential intervention needs to take place (Noor, 2008). Robert Yin stated that case studies should be used when the research covered a phenomenon which was not possible to separate from the context (Yin, 1981). This study desires to recommend design concepts to develop TPACK within higher education teacher professional development programs and a case study will allow the researcher to do this through examining the knowledge process of these teachers (Yin, 1981) in their classroom context.

A multiple case study was chosen to discover if multiple Grade 9 mathematics teachers are at the same level of TPACK. The benefit of a multiple case study is that the researcher can "explore the differences within and between the cases" and "replicate the findings across cases" (Baxter & Jack, 2008: 548). This means that multiple teachers have been examined to see if these gaps occur across the cases and across the different quintiles at the schools.

3.4 Data collection

Case studies need to involve multiple forms of data. Case studies are not limited to using only one type of data and it is important to use different data sets to answer your research questions (Tashakkori & Teddlie, 2009). Because of this reason, the researcher chose to collect data from multiple sources and these were analysed using a rubric specifically designed to measure TPACK.

1. Video recording of participants' lessons
2. Lesson artifacts
3. Semi-structured interviews with participants

3.4.1 Video recording

Video recordings were done of each of the three teachers' lessons. The researcher recorded one 60-minute lesson from Teacher A, two 30-minute lessons from Teacher B, and one 45-minute lesson from Teacher C. Having access to an observation of a lesson provided an opportunity to see these Mathematics teachers in their classroom context in real time (Tellis, 1997). This meant that the raw data of classroom teaching could be analysed against TPACK. Video recording allows for qualitative investigation that is able to record and give the researcher the ability to identify areas of truth would could, otherwise, be hidden (Penn-Edwards, 2012).

A cell phone was set up on a tripod and placed at the back of each classroom, and recorded the lessons in their entirety. The fixed camera approach was chosen so that the researcher had the role of observer instead of cameraperson (Heath, Hindmarsh & Luff, 2017). With the camera placed at the back of the classroom, the researcher was able to record the lessons in their entirety and had access to a "consistent view of the stream of action" (Heath, Hindmarsh & Luff, 2017: 5). This also meant that the researcher was not in the room whilst the recording happened. The researcher purposefully did this to make sure that the teacher, or the learners, does not change due to an unknown presence in the classroom (Tellis, 1997). The camera was placed at the back of the classroom as this allowed the researcher to have a full view of action (Heath, Hindmarsh & Luff, 2017), making sure that no interactions with the learners were missed if the teacher moved around the classroom.

3.4.2 Lesson artifacts

Case studies need to involve multiple forms of data. Case studies are not limited to using only one type of data and it is important to use different data sets to answer your research questions (Tashakkori & Teddlie, 2009). In this case, lesson artifacts from the recorded lesson were also analysed .

The researcher collected the lesson plans from the teachers and any worksheet, presentation, or other material that the teacher used during the lesson. Lesson artifacts a teacher uses in the classroom (Niess, van Zee & Gillow-Wiles, 2010) and lesson plans (Harris, Grandgenett & Hofer, 2010; Lyublinskaya & Tournaki, 2014) are another way of researchers assessing TPACK. It is useful to analyse these to see if what occurred in the classroom and what was implemented by the teacher was planned or if there was a divergence (Hofer & Grandgenett, 2012). For example, a teacher may demonstrate low TPACK in a lesson recording for multiple reasons such as a lack of electricity during loadshedding or devices in the classroom not working, however the lesson plan might reflect a higher level of TPACK and it was just able to be demonstrated in the actual lesson.

3.4.3 Semi-structured interviews

The researcher also interviewed each of the three participants. These interviews were done using semi-structured questions based on Niess et. al (2010) questions that examined on a teacher's TPACK when using spreadsheets for algebraic reasoning.

Interviews are a very important source of data in case studies and can be used to corroborate previously collected data (Tellis, 1997). The researcher chose a semi-structured interview format, both virtual and face-to-face that was made up of multiple probing questions that were sequenced under specific themes (Kvale, 1996). These themes allowed the researcher to explore the teachers' TPACK further through their choices, beliefs, attitudes, and behaviours (Robson, 2002). Semi-structured interviews allow for a greater form of flexibility, and the researcher is able to change or adapt wording in the questions, and use further exploratory questions based on what the researcher sees as most appropriate in the situation (Robson, 2002; Kvale, 1996). Open-ended interview questions are also appropriate as, whilst they are structured and the same questions are asked for each participants, the researcher is able to ask further probing questions in order to go deeper (Turner, 2010) and could adapt the questions as the interview proceeded.

Using semi-structured interview questions allows the researcher the space to have a reciprocal and interactive conversation that can help make the participants feel that they are in a safe environment and, in turn, give the interviewer "privileged access to the subject's lived word" (Kvale, 1996: 125). In this case, using standardized open-ended interviews aided in corroborating the analysed data from the classroom observations. These interview questions were not the main source of data being analysed as they can be cumbersome to analyse accurately (Turner, 2010); but rather were used as a tool to probe further how the teacher felt about their practice in the areas of TPACK.

3.4.4 Interview schedule

An interview schedule was developed for the semi-structured interview questions. These questions needed to probe the teachers' theoretical understanding of TPACK over their practical demonstration of it in the recorded lessons.

Questions were adapted from Niess et al.'s (2010) interview protocol. The questions explored four themes of TPACK development, and are discussed further in this chapter under *Data Analysis*.

Prior to the main interview, the questions were discussed and analysed with an Education department colleague who specializes in educational technology. Through this discussion, the language was revised, and further discussed with the researcher's supervisor, before being finalized.

The revision of the questions concerned the level of the language for South African teachers, and re-phrasing of questions to make them more open-ended, and to enhance the questions' clarity.

3.5 Data production

COVID-19 severely hampered the researcher's ability to find participants for the study. The study was ready to begin the data collection process by March of 2020 but COVID-19 forced school closures, rendering it not possible to observe classroom lessons until later that year.

The researcher participated in a meeting with the head of General Education Training (GET) and the head curriculum advisor for GET mathematics in the Western Cape over Zoom after the initial 6-week lockdown was completed and schools were not yet returning. The researcher discussed with them the potential plan to only use lesson plans and lesson artifacts, along with interviews with the teachers but the researcher was advised against doing this. At the time, the Western Cape Education Department (WCED) was designing and delivering online learning and teaching lesson plans to all teachers and it was clear that this would affect the reliability of my results, as the researcher would be assessing a curriculum development's TPACK and not the actual Grade 9 teacher's TPACK. It was decided that the researcher would postpone the data collection until Grade 9 learners and teachers had returned to school.

In the meantime, all curriculum advisors in the Western Cape were sent an information cover sheet about the study and teacher names and these advisors sent through contact details of teachers from different schools to the researcher.

The researcher also made contact with the method subject lecturer at one of the leading Western Cape tertiary Education department to find current pre-service Grade 9 mathematics teachers who would participate in the study. As mentioned earlier, the curriculum advisors gave lists of teachers to contact; the researcher worked through the list to find teachers who would participate in the study. Due to COVID, this posed a struggle and the researcher had to accept the teachers that were able to participate.

Schools opened up again in October of 2020 and initial telephonic and Whatsapp contact was made with teachers and PGCE students to establish if they would participate in the study and to set up meetings for permission.

The data collection process was conducted in late October and early November. In some cases, the researcher returned to the school over a two-day period to record lessons and engage in the one-off qualitative interview. One of the teachers had their interview conducted over Google Meet in order to limit face-to-face contact for both the researcher and their safety. After the camera was set up to record the lessons, the researcher spent the time either in their car or sitting outside of the school's reception area, as per the school's COVID-19 visitor regulations.

The interviews were conducted in English and the researcher made sure that they focused on actively listening to what the participants were saying. The researcher attempted to limit interruptions and prompted only to help expand on their answers, as per Niess' (2010) interview schedule. The main focus was to keep asking questions and have the participants answer as fully as possible. To lower the participants possible interview anxiety, the researcher attempted to show enjoyment of the interview (Robson, 2002).

Field notes were taken at each of the schools. This was done so that the researcher could record contexts that could be important to how the data was interpreted, and remind them of situational factors that could add to the richness of the data (Sutton & Austin, 2015).

3.6 Data management

This study is qualitative and it was necessary to make sense of the data from the multiple sources of teacher interviews, teacher lesson recordings, and further teacher documents (Caudle, 2004). The data management needed to remain true to the participants (Sutton & Austin, 2015) and have a procedure that means all data management was consistent and all instances assigned to the same categories (Silverman, 2010). It is also extremely important that the research measures what the study planned to measure (Robson, 2002).

Data was transcribed and stored using Cloud storage. Data organization is extremely important otherwise the researcher will have "data identification, access, and retrieval problems" (Caudle, 2004: 419). Data was organized in separate folders for each school labelled School A, B, and C. After uploading the data into the Cloud, any recordings and content was deleted from the researcher's computer.

The management of data followed three separate processes: (1) transcription of the lesson recordings and interviews (2) the design of the data analysis frameworks (3) the reporting of the data analysis. Transcriptions of the recordings will remain in folders hosted the Cloud and these folders remain in the Cloud, granting access to the transcriptions for the reviewers of this study.

3.7 Transcription

Transcribing the interviews and the lesson recordings must never be thought as a simple technical detail (Silverman, 2010). It was carefully conducted at each stage of the process.

The interviews with Teacher A and B were uploaded to the Cloud from the cellphone application, *Voice Recorder*, which was used to conduct the interviews. Teacher C was recorded via *Google Meet* and automatically uploaded to the Cloud. The researcher was advised by a colleague to use the software, *Express Scribe*, as a dictation device as it allows the transcriber to slow the recorded speech so that it matched my typing speed. Through this software, there was minimal loss to the sound and diction quality. When transcribing, the researcher chose to write what they heard and did not use transcription symbols to show any speech tics, intonation, or stresses (Silverman, 2010) because this study is more interested in how a teacher uses technology in their classroom over their classroom mannerisms. It was noted through the use of ellipsis if there were pauses as these could show hesitation on the behalf of the teacher when using technology.

After finishing transcribing each recording, the researcher re-listened to the recordings and compared them to the first round of transcripts, making sure to record any changes to ensure accuracy. The transcripts were then saved onto the Cloud in the folder to the corresponding school, and a copy was printed.

With the transcriptions completed and a copy of all lesson artifacts, the researcher was able to progress to the stage of data analysis. The video recordings have been backed up onto an external hard drive and removed from the Cloud storage folders.

3.8 Data analysis

The analysis of all data was under four thematic topics by the use of a guiding rubric with descriptors.

Lyublinskaya and Tournaki developed the rubric in 2011 to measure and assess the changes "in how teachers integrate technology into mathematics teaching and learning" (Lyublinskaya & Tournaki, 2011: 4397). The rubric is structured on a TPACK framework analysing teacher growth of the use of technology integration in their classroom through five progressive levels which appear in each of the four TPACK descriptors (Lyublinskaya & Tournaki, 2011).

3.8.1 Primary analysis

The four TPACK descriptors guided the data analysis which was an inductive whole-to-part approach in reasoning (Erikson, 2006). These came from Niess's (2005) adaptation of Grossman's (1989) central components of PCK. These four descriptors provide a framework to view teachers' TPACK development (Niess, 2005).

1. An overarching conception about the purposes for incorporating technology in teaching mathematics;
2. Knowledge of students' understandings, thinking, and learning of mathematics with technology;
3. Knowledge of curriculum and curricular materials that integrate technology in learning and teaching mathematics;
4. Knowledge of instructional strategies and representations for teaching and learning mathematics with technologies (Niess et al., 2009: 8).

A five-stage sequence of innovation adopted guided the next stage of the data analysis.

TPACK is something that is developed in teachers and so Niess, Sadri, and Lee 2007) proposed a model to show TPACK development which emerged from Everett Rogers' (1995) model showing the decision process people make when adopting a new innovation. This five-stage process follows a sequence by which a person decides whether they will adopt or reject the new innovation presented to them (Niess, 2007). This can be seen as a move from PCK to TPACK. For this study, this sequence is applied to teachers and their ability to integration of technology into the subject of Mathematics as they move up the sequence and develop their TPACK.

1. Recognizing (knowledge), where teachers are able to use the technology and recognize the alignment of the technology with mathematics content yet do not integrate the technology in teaching and learning of mathematics
2. Accepting (persuasion), where teachers form a favorable or unfavorable attitude toward teaching and learning mathematics with an appropriate technology
3. Adapting (decision), where teachers engage in activities that lead to a choice to adopt or reject teaching and learning mathematics with an appropriate technology.
4. Exploring (implementation), where teachers actively integrate teaching and learning of mathematics with an appropriate technology
5. Advancing (confirmation), where teachers evaluate the results of the decision to integrate teaching and learning mathematics with an appropriate technology (Niess et al., 2009: 9)

Each of the four descriptors has two performance indicators developed for all of the five-stage levels (Lyublinskaya & Tournaki, 2011) . Each descriptive is analysed as per the five-levels that move a teacher from TCK to TPACK developed by Niess et al. (2009). The range of scores a teacher can achieve are from 0 – 5. This number can be an integer when both performance indicators have been met) or a half-integer (one out of the two performances are met), and scores are assigned for each descriptor independently (Lyublinskaya & Tournaki, 2011).

Descriptor		Recognising (1)	Accepting (2)	Adapting (3)	Exploring (4)	Advancing (5)
Overarching conception	Teacher					
	Learner					
Knowledge of students	Teacher					
	Learner					
Knowledge of curriculum	Teacher					
	Learner					
Instructional strategies	Teacher					
	Learner					

Figure 8: TPACK rubric (Kaplon-schilis & Lyublinskaya, 2018)

The recordings of the participants' lessons were analysed using the TPACK rubric. Through the use of the rubric, participants were given a score for each performance indicator of the descriptive levels. The researcher also collected lesson plans and material used during the lesson by the teacher and the learners. This additional data was used by the researcher to further explain and reason the score given to the participant on the TPACK rubric.

The researcher used their own knowledge and experience in teacher professional development with ICT integration to make retroductive reasoning on the participants' practice through the observations on the lesson recordings. Retroductive reasoning involves a researcher using their own inferences from both data and observations to create an explanation of the occurrences (Mouton, 2001). It is important to note that another researcher engaging with the recording and the rubric may interpret the material in a different manner, depending on their inference of the observations. The lowest score across the four descriptors of the TPACK Levels Rubric is the teacher's TPACK development (Kaplon-Schilis & Lyublinskaya, 2020).

3.8.2 Secondary analysis

After analysing the lesson recordings and additional data against the TPACK rubric, the researcher analysed each of the teacher's rubric scores against the specific domains of knowledge. The researcher compared the results of the lessons with the semi-structured interview questions developed by Niess et. al (2010). The researcher adapted the original questions to be phrased with a focus on technology as a whole instead of specific use of spreadsheets, as done in the original study.

It was important to note that these results on the rubric after the recorded lesson are not definitive as they are only a snapshot of the teachers' practice. The researcher took into account the answers the teachers gave to the semi-structured interview questions. These answers gave a further insight into what the teacher's practice may be outside of this small classroom sample. The researcher used inductive reasoning to interpret the answers in the teachers' interview questions and further commented on their TPACK for each of the four descriptors. These answers helped the researcher to further comment on the teachers' TPACK in reference to their thinking and general overall practice.

3.9 Reporting on the data analysis process

Chapter 4 details the findings from the data analysis process. It includes a detailed description and discussion of each teacher's lesson plan analysed against the TPACK rubric, and provides reasons and evidence for each descriptor of the rubric.

The report on the analysis findings takes the form of a descriptive breakdown of each teacher's lesson guided by each of the four descriptors. The teachers are individually introduced with a short description of the lesson outcomes and actions.

3.10 Ethical considerations

The researcher gained ethical clearance from the School of Education at the University of Cape Town. Post gaining this clearance, the study was sent through to the Western Cape Education Department for approval to gain access to schools. This was all received before the researcher began to contact any schools or speak to any WCED curriculum advisors.

At the start of each recording session at a school, and each interview, the purpose of the research was explained to the participant, along with the measures that the researcher had taken to ensure their anonymity. As a video records the person, video recordings can be seen as a form of data that, unless participants are masked or filtered, that can never truly be anonymous (Derry et al., 2010). Because of this, the researcher has made sure that the video footage access is restricted, and also the names of the schools and the participants. (Derry et al., 2010). All three teachers signed a waiver that gave their consent to being video recorded and interviewed. They were also provided a copy of this for their own records (Robson, 2002). The researcher informed them that their participation was voluntary and that they could decide to withdraw at any point of the study.

Because the researcher was recording a lesson as it happened, they needed to consider that learners in the classroom would be recorded. This meant that prior to the data gathering and recording, the teachers were given a participation consent form that needed to be signed by the parents of the children in the lesson being recording. The learners were not the subject of the study and this was made clear to the parents. It also made it clear that their children's names and the name of the school would remain anonymous.

The confidentiality of the teachers and the learners was at the forefront of the researcher's mind. Because of this, all data has been labelled as School A, B, or C, and the teachers have been given pseudonyms. At no point are the learners' names mentioned and in any transcribing, they are just referred to as "learner" with no name or gender indicated.

In conclusion …

This chapter has explored the research design process, making sure to include methodological choices in regards to the production of data, management of data, and the analysis of the data. A discussion post this explores and elaborates on the ethical considerations taken when planning the study and the threats to the validity that needed to be considered and overcome.

The following chapter analyses and explores the data obtained from the lesson recordings, lesson artifacts, and interviews with the three participants drawn from three schools in Quintile 3 (1 school) and Quintile 5 (2 schools).

Chapter 4: Data analysis

This chapter gives a detailed analysis of the data collected in this study. The first stage of the analysis examines the teachers' recorded lesson and their lesson artifacts and assesses their TPACK using a rubric. The second stage of the analysis looks at the interview done with the teacher and compares this with the results of the rubric analysis.

Each teacher's recording lesson in combination with the lesson plan and teaching artifacts was analysed using the TPACK Levels Rubric for Instructional Technology Applications in Teaching Mathematics and Science (Kaplon-schilis & Lyublinskaya, 2018).

In the following analysis, criterion 1 reflects the teacher actions in each component, and criterion 2 reflects the learner actions in each component. The teacher's overall score for each component is a combination of the two criterion. For example, if the teacher action scores 1 and the learner actions scores 2, the teacher's overall score is 1.5 for this component.

4.1 School A: Teacher A (Rose)

4.1.1 Description of Rose's lesson

Teacher A, or Rose (not her real name), was assessed using a Grade 9 mathematics lesson around the concept of the classification of quadrilaterals, focusing on diagonals. The skills that Rose aimed to develop within the learners were investigation, observation, recording, and communication. Learners needed to have the pre-requisite knowledge and skills to do basic identification of quadrilaterals'' angles and sides; they needed to be able to describe quadrilaterals based on identification of their sides and angles; and they also needed to be able to record findings on their own. The class was around 21 learners and they all worked independently.

In order to assess her learners' previous knowledge on identification of quadrilaterals and shapes, Rose started her lesson by projecting images of these shapes onto the SMART board and asked the learners to identify and describe what they knew about them. Rose worked with the learners to formulate a definition for a square and then moved onto the investigation part of the lesson. Rose used a short video that demonstrated to learners how to fold a piece of paper into different shapes. At certain points, Rose paused the video to discuss the shapes and allow learners to record their findings. The video was sourced on YouTube, and saved on Rose's Google Drive.

After the investigation was completed, Rose used the SMART Board to demonstrate how to draw a shape with its diagonals, angles, and proper notations. After the demonstration, volunteers were invited to the front, and used content developed in the SMART Notebook in order to draw the required shape with its diagonals, angles, and proper notations.

Rose then used the context of family likeness as context for shapes and how they can appear different but have the same properties. In order to cement this point with her class, Rose read a story about quadrilaterals to her class and had them create a quadrilateral family tree in their workbooks.

The lesson concluded with learners working on a paper worksheet that Rose handed out to them.

Unpacking Rose's Rubric indicators

4.1.2 Examining indicators for Overarching Conception component of TPACK

Rose's lesson met the criterion for the Recognising level of the overarching conception component of the TPACK levels rubric. According to the rubric, Rose scored an overall 1 for this component: a 1 for the teacher-led section, and a 1 for the learner-led section. This was reflected on the rubric through teacher activities that motivated and gained learner attention, and learner activities that allowed for drill and practice of the learned content.

Criterion 1a:
Rose used her whiteboard and the SMART Notebook software to project images (See figure 9) at the start of the lesson to grab learner attention and motivate them to pay attention to the content.

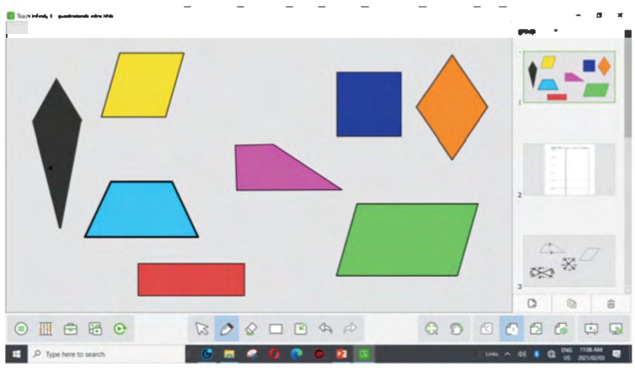

Figure 9: Example of SMART Notebook software used in the Grade 9 mathematics lesson

The content presented using the SMART Notebook software was a static image. Rose stood in front of the projector and asked the whole class:

> *Okay. I just want you to look at the picture. And tell me, let me just scroll up, what do you see? What are these shapes?* (Rose Recorded lesson; lines 11-12)

This fits with the criterion at the recognizing level where the teacher uses technology for learner motivation and to gain the learners' attention. The use of the technology was not to aid in learning a new topic.

> *90 degree angles. So most of the time that is the answer that we will give. Yes both sides are equal umm and it has got 90 degree angles. But we are going to focus a bit more on diagonals. Okay. Knowing the properties of the shape, how to determine the unknown angles, unknown sides. For example, umm, say one of you go missing. You go missing for a day. Your mummy panics. Will your mummy go to the police and say my daughter is gone, she is my daughter.* (Rose Recorded lesson; lines 39-44)

Rose did not use the projected images to introduce the new content of the lesson, and rather chose to engage the learners in this through a physical demonstration at the front of the classroom. She talked the learners through the new content and offered them a hypothetical situation to create connections. This situation was posed to the learners with some basic whole-classroom questions asked.

Criterion 1b:

Rose used a video to help learners fold the pieces of paper that were handed out to them into the shapes that they were learning about.

Figure 10: Example of video played to Grade 9 mathematics class

This fits the criterion for the Recognising level as the content was passive and did not aid in subject matter development. Once the learners had followed the instructions, Rose would pause the video and then talk the learners through the subject matter and what they should be learning.

> *90 degrees. Right. So if I take my square and I fold it half like this, with the two corners touching and I know my corners there are equal, my angles are equal there. I fold my angles over to touch each other, by the corners. Okay. So I know my angles are all equal. Right. Okay. Now. My angles are equal. I know that an angle of a square is equal to 90 degrees, right?* (Rose Recorded lesson; lines 101-104)

In some occasions, Rose would speak over the video that was playing to offer learners further instructions and directions.

> *Teacher walks back to her desk and sits by the computer. Video starts playing again with instruction to fold a similar shape. Teacher talks over the video.*
>
> *Teacher does demonstration from behind her desk.*
>
> *Teacher: Open. Open your square. We're starting from here now. And you fold it over in half. You are making a little nappy. Okay. May I continue?* (Rose Recorded lesson; lines 213-217)

In order for Rose to move above the first level, she would need the technology to aid in subject matter development and for the technology to be used in a way that differs from teaching without the technology (Kaplon-schilis & Lyublinskaya, 2018)

Criterion 2:
The learners in Rose's classroom were using technology at a 'Recognising' Level where their use of technology-based activities only allowed the learners to practice the subject matter that they had learned (Kaplon-schilis & Lyublinskaya, 2018).

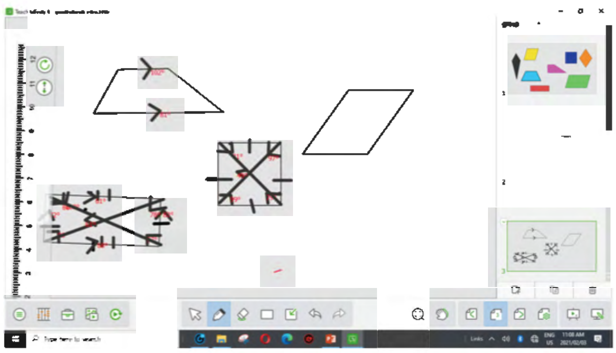

Figure 11: Example of SMART Notebook software used by learners in Grade 9 classroom.

Rose invited learners to the front of the classroom where they had to identify and draw the correct diagonals, angles, and mathematical notations. Learners were given the opportunity to practice their memory of what they had learned about the shapes and their angles during the paper folding activities.

Had Rose used the technology for learners to engage in inquiry tasks, this part of the rubric would have scored on the 'Adapting' or higher level.

4.1.3 Examining indicators for Knowledge of Students component of TPACK

Rose's lesson met the criterion for 'Recognizing' level of Knowledge of Students. According to the rubric, Rose scored a 1 for this set of criterion, with a 1 for both teacher-led and learner-led actions. This was reflected on the rubric through the teacher use of technology in a way that didn't support further thinking, and learner activities that gave the one or two learners who engaged the space to practice what they had learnt (Kaplon-schilis & Lyublinskaya, 2018).

Criterion 1:

Rose's use of technology with the learners only scored her a 1 on the rubric. Rose used the video recording in this lesson to lead learners and let them follow in order to learn how to fold their paper into shapes.

> *Video starts playing again with instructions and some of learners continue to fold whilst some just watch the video.* (Rose Recorded lesson; lines 219-220)

This use of technology did not aid or support learners in either their thinking or their ability to learn the new content (Kaplon-schilis & Lyublinskaya, 2018) as the learners either followed along with the video instructions without thinking, or just watched and did not fold at all.

After playing the video, Rose would often re-explain how to fold the paper and demo it again herself, meaning that the use of the technology was actually void and did not serve a purpose in the lesson to aid learners in their thinking.

> *Okay, so now. Now we have a kite. Okay. If I fold my kite. First I see that I've got two adjacent sides equal length. 2 adjacent sides are equal. If I fold that, I can see one set of opposite angles are equal. Alright? One set. Because if I fold it like that you can see the one is smaller. Correct? If you look carefully, you can see that the rhombus diagonal, he cuts the angles there in half. Let's see what is the size of the angles where they bisect. 90 degrees. 90 degrees. 90 degrees. 90 and 90. Right. So diagonals bisect each other perpendicularly. I am going to repeat what we found. We said adjacent sides equal … we said 1 pair of opposite angles equal. By the diagonals. We said that the rhombus diagonal halves or bisects the angles. And the diagonals bisect each other perpendicularly.* (Rose Recorded lesson; lines 222-230)

Rose essentially repeats what the video told the learners to do with the paper and she also is the one who explains and teaches the angles and diagonals of the shape. The technology of using the video in class is not what aids and supports the learners in learning about these shapes, but rather what Rose herself tells them.

Rose also projected an image of herself and her family onto the SMART Board when she introduced a new concept to the learners.

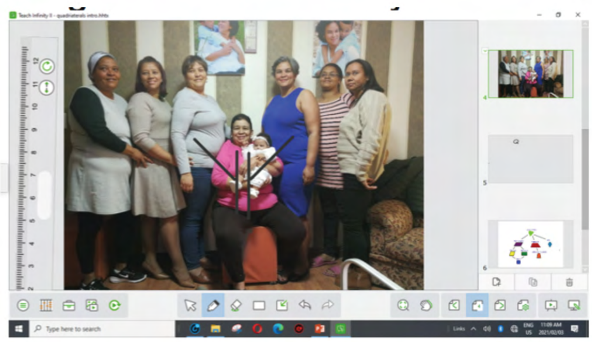

Figure 12: Image projected onto the SMART Board to introduce content

Rose attempts to make a connection between her family and the mathematics content, but again it is not the use of technology that does this but rather Rose's explanations that she gives the learners.

> *Teacher puts a photo of her family up on the whiteboard. She points to each person on the photo.*
>
> *Teacher: So this is my Molly. That is my sister, that's my sisters in law. We all belong to one family. Right. Do we all look the same?*
>
> *Learners: (Chorus) No. Some learners say yes.* (Rose Recorded lesson; lines 327-331)
>
> *Teacher: We've got my mummy's nose we've got this we've got that. But there are certain things that are different. Just like our quadrilaterals. It's easy to be confused between a parallelogram and a rhombus, right, because they belong to one family: the quadrilateral.* (Rose Recorded lesson; lines 342-346)

Rose could have achieved this same effect by telling the learners this without using the projected photograph. In order for this to have scored higher in the component, Rose needed to use the technology to develop the learners' conceptual understanding of the mathematical content (Kaplon-schilis & Lyublinskaya, 2018).

Criterion 2:
The digital materials that learners used only gave them a platform to practice the identification of angles and diagonals, meaning that the learner criterion only scored a 1 on the rubric.

Figure 11 shows how selected learners came to the front of the classroom and used the digital material from the SMART Notebook to practice what they had learnt about angles during the folding and measuring activities in the earlier part of the lesson. Learners were not pushed to do further mathematics themselves or apply what they had learnt to different situations.

> *Teacher: Okay I need a volunteer. This is the easiest one. Who wants to do this one? Nice and easy. All you need to put in the properties for the trapezium. Do you want to?* (Rose Recorded lesson; lines 286-287)

In this scenario, the learner came to the front of the classroom and had to draw in what they had investigated with the folded paper. Rose offered the learner advise, and the rest of the learners in the classroom also called out what they could remember to help this learner complete the practice task.

4.1.4 Examining indicators for Knowledge of Curriculum component of TPACK

When it came to the component of curriculum knowledge, I was faced with a conundrum of what level to place Rose on for her lesson. The reason for this was that Rose used technology in two different ways in her lesson and each way scored her different on the TPACK Levels Rubric. For one way, she scored a level 1 and for the second way she scored a level 3. Because of this conundrum, I chose to take the middle ground and to score Rose as the 'Accepting' level 2 on the rubric.

Criterion 1a:
Rose's use of playing a video to help guide learners to fold paper into shapes places her on the 'Recognising' level 1 of the rubric. The video did not align with the South African Curriculum and Assessment Policy (CAPS) for Grade 9 mathematics and it was not used to

deliver the mathematics curriculum content. The connection to the curriculum content occurred after Rose paused the video and she further explained the shape.

> *Rose: Okay. So starting with what should you have in your hand?*
> *Learners: (chorus) Squares.*
> *Rose: Okay, squares. What do we know about the sides?*
> *Learners: (chorus) Both sides equal.* (Rose Recorded lesson; lines 94-97)

In order for Rose to move past 'Recognising', she would have needed the instructional technology used not only to align with the CAPS curriculum content, but also to offer the learners different manners of exploring the content (Kaplon-schilis & Lyublinskaya, 2018).

Criterion 1b:
The second way that Rose used technology in her lesson was to utilize her SMART Notebook software and model a curriculum-based task to her learners. The use of this to project images of the 2D shapes in the lesson helped to align the technology to the curriculum. According to the South African Curriculum Assessment and Policy (CAPS), learners need to "revise and write clear definitions of quadrilaterals in terms of their sides, angles and diagonals" and be able to distinguish between the types of quadrilaterals (Department of Basic Education, 2011: 31). Rose attempts to achieve this by demonstrating to the learners in the class how to identify the sides, and angles of a square.

> *Rose: Okay. So we know each angle is equal to 90 degrees, right. So what are the interior angles of a quadrilateral equal to?* (Rose Recorded lesson; lines 281-282)

Figure 11 shows how she used the SMART Notebook to model identification of sides, angles and diagonals of a quadrilateral, which is aligned with above curriculum content. Through the use of drawing on the SMART Notebook content, Rose has replaced a paper worksheet with no technology into a technology-based task on the SMART Notebook (Kaplon-schilis & Lyublinskaya, 2018).

This use of technology scored Rose an 'Adapting' level 3 on the Rubric.

Criterion 2a:

The learners' engagement with the video helping them fold paper into geometric shapes did not offer the learners any support to make and further connections in the CAPS Grade 9 mathematics curriculum. Learners merely follow the video to fold the paper into shapes, and after the video is paused, Rose further explains the content.

Because there are no opportunities for connections with the CAPS curriculum topics, this criterion scores a 'Recognising' level 1 on the Rubric (Kaplon-schilis & Lyublinskaya, 2018).

Criterion 2b:
The learners in Rose's class were given the opportunity to come to the front of the classroom and engage with the quadrilateral shapes. This engagement with the technology helps the learners with their basic understanding of this specific curriculum topic, but they need to be guided by the teacher (Kaplon-schilis & Lyublinskaya, 2018).

> *Rose: It's fine. That one actually needs because you need to say this side is also equal, right, so put a line there and arrow. Good. So we need another set of arrows.*
> (Rose Recorded lesson; lines 315-316)

The learners do not expand on any of the mathematical ideas and are not given an opportunity to explore the curriculum topic with the technology, scoring this criterion an 'Adapting' level 3 on the rubric.

4.1.5 Examining indicators for Instructional Strategies component of TPACK

Another small conundrum was addressed when assessing Rose on the rubric for the criterion of Instructional Strategies. Whilst Rose could be placed under level 3 'Adapting' for the teacher-led use of technology, the use of it is limited to two learners and the rest only watch a teacher-led form of instruction. Because of this, I decided to score Rose a level 2 under 'Accepting' for her instructional strategy use of technology. The learner-led criterion scored Rose a level 1 for 'Recognising' bringing her score for this component to a 1.5.

Criterion 1a:
Rose uses the technology in her classroom to instruct and give demonstrations. This is most seen in how Rose is the one controlling the video played to the learners. The learners are not

given the opportunity to explore this content on their own, but rather Rose chooses when to pause the video and when to continue playing.

> *Rose walks back to her desk and sits down.*
> *Rose: All good?*
> *Learners: (chorus) Yes.*
> *Rose starts to play the video again. The video continues showing learners how to fold the paper into a new shape. They are folding into a rhombus. Rose pauses the video.*
> *Rose: I hear, uh uh, do I need to repeat this one?*
> *Learners: (Some say) Yes miss.* (Rose Recorded lesson; lines 231-237)

If the video had been given to each learner to play at their own speed and to help Rose deliver the learning objects, she would have been able to score higher on the rubric; however the way that she uses it places her on level 2, 'Accepting' of the technology.

Criterion 1b:
Rose does allow for learners to come to the front of the classroom and to engage with the instructional material. She is, at all times, in control of the learner's exploration of the content, and even offers guiding advice to both of the learners as to what they need to draw on the SMART Notebook content.

> *Rose: Okay I need a volunteer. This is the easiest one. Who wants to do this one? Nice and easy. All you need to put in the properties for the trapezium. Do you want to?*
>
> *Rose hands a marker pen to a learner who has come to the front of the classroom*
>
> *Rose: Come. What were the properties for a trapezium?*
> *…*
> *Rose: Parallel so we're going to make a little arrows.* (Rose Recorded lesson; lines 286-294)

Whilst the above usage of the technology is a deductive approach, and should be scored as a level 3 for 'Adapting', Rose only engages in this behavior with two learners in the classroom. I chose to reduce this to a level 2 on 'Accepting' because, for the rest of the class of learners, this form of instruction does not allow for any learner exploration and would be purely teacher-led.

Criterion 2:
Rose's use of technology in this lesson only allows for learner drill and practice. The learners are only able to use the technology to drill their understanding of shapes through watching the folding video, and then practice what they have learnt through Rose's explanations by drawing on the SMART Notebook content later on in the lesson.

The use of the technology on the behalf of the learners does not utilize any instructional strategies that aid in delivering information or engage in any learner reflection. The learners are not given any opportunities to use the digital materials for reasoning and justification of what they have learner.

This means that the learner actions under this component score a 1, or 'Recognising'.

4.1.6 Rose's final score on the TPACK Levels Rubric

	Recognising	Accepting	Adapting	Exploring	Advancing
Overarching conception	1				
Knowledge of students	1				
Knowledge of curriculum		2			
Instructional strategies	1.5				

A teacher's overall TPACK is the lowest number that they scored across the components, so Rose's TPACK sits at a level 1 and she is rating as 'Recognising' when it comes to integrating technology into her classroom.

4.2 School B: Teacher B (Daisy)

4.2.1 Description of Daisy's lesson

Teacher B, or Daisy (not her real name), was analysed using a Grade 9 Algebra Mathematics lesson. This lesson was an introduction to solving algebraic equations and is a snapshot of a 4-lesson sequence building on difficulty of the algebraic equations. Learners needed to utilize their Grade 8 knowledge of equations, and worked with the Active Living textbook (workbook). Daisy did not include any outcomes or objectives in her lesson plan. The number of learners in the classroom was 22 and they were attending school on an alternative basis.

Daisy started the lesson by revising Grade 8 equation knowledge. She wrote equations on the whiteboard and engaged in whole class solutions. This remained the theme for Daisy's lesson. She projected the necessary content onto the whiteboard, and then wrote examples on another board for learners to see.

The main content of the lesson was by explaining how to solve a basic algebraic equation. Daisy used a technique that she called 'the first level'. After demonstrating this through multiple examples, Daisy moved on to 'the second level'. She utilized the projector with more explanations and solved further examples in front of the learners. The learners were given a 5-minute period to solve examples from the Active Living textbook near the end of then lesson.

The lesson ended with Daisy giving the learners homework to do before their next lesson.

Daisy utilized a call and repeat to emphasize content and knowledge amongst the learners. She would repeat important phrases and answers, and expect the learners to chant along with her.

Unpacking Daisy's Rubric indicators

4.2.2 Examining indicators for Overarching Conception component of TPACK

Daisy's lesson scored an average of 1 on the TPACK levels rubric. She scored a 1 of 'Recognising' for the teacher-led criterion, and a 1 for the learner actions criterion. This was reflected on the rubric through Daisy presenting new ideas mostly through the use of no technology, and the learners not engaging in any technology tasks (Kaplon-schilis & Lyublinskaya, 2018).

Criterion 1:

Daisy utilized technology to project images from the textbook onto the whiteboard. Both she and the learners then read these projected images and used them to do work on the whiteboard with markers.

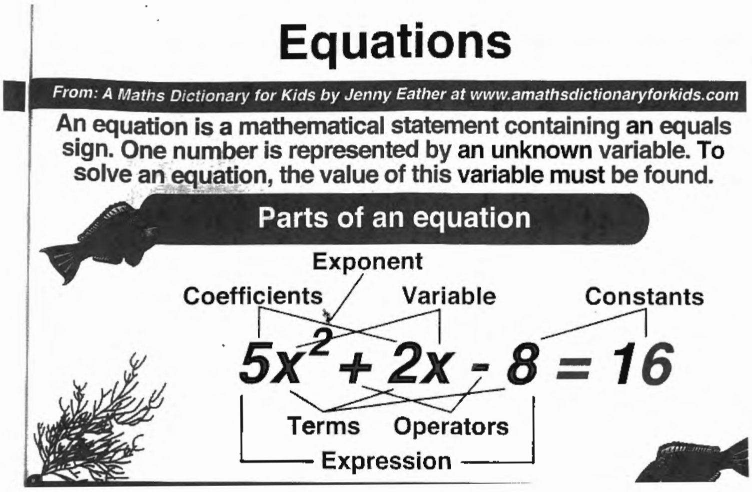

Figure 13: Image of content projected onto the whiteboard

The use of technology to do this was unnecessary as the learners had a copy of this in their own textbooks. The actual work that was done to introduce the content was done by Daisy writing on the whiteboard. This use of technology scored Daisy a 1 for 'Recognising'.

Criterion 2:

The learners were not given any tasks that involved the use of technology to make connections or use content. The only task that the learners engaged with that involved technology was to choral read content off of the projected image on the whiteboard together.

4.2.3 Examining indicators for Knowledge of Students component of TPACK

For this set of criterion, Daisy scores 1 overall on the TPACK levels rubric for both teacher-led and learner-led criterion. This was because Daisy did not use technology in a manner that supported learner thinking and learning of then new content, and the learners were only involved in the technology as a form of drill (Kaplon-schilis & Lyublinskaya, 2018).

Criterion 1:

The content that Daisy used and was projected onto the whiteboard did not help to support learner thinking and learning about the new content. Daisy chose to project photocopied pages from the learners' textbook as a form of explanation. The learners were not given time to engage with the material and merely read it off of then board. The content being projected also did not extend the learners nor aid them to develop their higher order thinking skills to better understand then mathematics content (Kaplon-schilis & Lyublinskaya, 2018).

Criterion 2:
Learners engaged with digital materials that were projected onto the whiteboard. This content was used a choral drill that had the learners reading the content off of the whiteboard. Daisy did not leave room for the learners to take meaningful action on the content or to see what consequences these actions had on the mathematical content.

> *Daisy: Sorry, sorry about that. (points at the whiteboard when it comes back on) and thank you?*
>
> *Learners: (all choral read off of the slides)*
>
> *Daisy: Good. That is the explanation for the?*
>
> *Learners and teacher: The equation.* (Daisy Recorded Lesson; lines 53-57)

4.2.4 Examining indicators for Knowledge of Curriculum component of TPACK

Daisy's scoring on this component of the rubric places her on level 1 for 'Recognizing'. Her use of technology as the teacher, and the learners' use of technology is both not aligned with the curriculum and neither does t help learners make connections between the CAPS curriculum topics (Kaplon-schilis & Lyublinskaya, 2018).

Criterion 1:
Daisy's use of projecting images onto the whiteboard does not align with any curriculum CAPS topics. It is not a different form of learning through the use of technology and neither does it challenge the traditional CAPS curriculum. This means that she shows a level 1.

Criterion 2:
The only task that learners engage with that involves technology is to read off of the projected image on the whiteboard. This task does not help the learners make any

connections between curriculum topics and it does not aid in creating a deeper understanding of the mathematics topics in the CAPS curriculum or even outside of it.

4.2.5 Examining indicators for Instructional Strategies component of TPACK

Daisy scores an overall level 1.5 for 'Recognising' on the TPACK rubric for her use of technology within the criterion for instructional strategies. For the teacher-led criterion she scored a 2 for 'Accepting', but for the learner-led criterion she scored a 1 for 'Recognising'.

Criterion 1:
Daisy used the technology herself in the lesson and the learners were not given an opportunity to explore the content through the use of technology. Daisy projected content onto the whiteboard and then read through it herself or had the learners read through it for her. She then would demonstrate what the content meant in relation to the mathematical equations, meaning that the use of technology and instruction was teacher-led.

Criterion 2:
The learners were not given any opportunities to reflect on the mathematical content, and the use did not give the learners a chance to make sense of the content or to engage in any reasoning and justification (Kaplon-schilis & Lyublinskaya, 2018). The only way that the learners engaged with the technology was to read content off of the whiteboard. This was in the form of a drill and it helped to practice the learners' understanding of certain algebraic terms.

4.2.6 Daisy's final score on the TPACK Levels Rubric

	Recognising	Accepting	Adapting	Exploring	Advancing
Overarching conception	1				
Knowledge of students	1				
Knowledge of curriculum	1				
Instructional strategies	1.5				

A teacher's overall TPACK is the lowest number that they scored across the components, so Daisy's TPACK sits at a level 1 and she is rating as 'Recognising' when it comes to integrating technology into her classroom.

4.3 School C: Teacher C (Myrtle)

Teacher C, or Myrtle (not her real name), is a recently qualified Grade 9 mathematics and science teacher. When I came to her school to record her lesson, unfortunately I was only able to gain access to her science lesson based on electricity, and renewable and non-renewable energy. Due to both COVID-19 regulations and the timing of the school engaging in assessments, I was unable to return to record a mathematics lesson. Because of this, I have not included the analysis of Myrtle's lesson and lesson artifacts.

This is, for interest sakes, included in the appendix under 'Myrtle Recorded Lesson Analysis'.

4.4 Analysis of the domains of knowledge

The following analysis examines each of these four domains of knowledge through interviews with the teacher compared with their results on the TPACK rubric through their lesson recordings and artifacts.

4.4.1 Overarching Conception of Incorporating Technology into Teaching Mathematics

This first domain of knowledge has a focus around what a teacher knows and believes about mathematics and how technology is able to support a learner's ability in learning mathematics (Niess, 2007). A teacher who has developed this knowledge area will have a strong foundation in their knowledge of mathematics and technology and this will mean that they will be able to make decisions about classroom instruction that best benefits the learners (Niess, 2007).

All three teachers in this study score a level 1 for this domain of knowledge. This means that they are all using technology for learner motivation and have not developed the knowledge needed for learners to develop a "deeper conceptual understanding of mathematics" (Kaplon-schilis & Lyublinskaya, 2018: 2077).

Part of the problem with this that can be seen in the data is that the teachers do not fully understand how technology can be used in the mathematics classroom. For example, Daisy has not expanded her understanding of what technology is and this means that she is not able to think past technology only being the physical vehicle that is used in the same manner as a textbook or a notebook. In her interview, when asked what digital technologies she is a constant user of, she was unable to think past the device itself and the basic applications that come with it:

> *Daisy: I am using a computer; I am using the whiteboard; I am also using the computer lab. I just collaborate all of them.* (Daisy Interview; lines 152-153)

When pushed further, Daisy could only express how she uses the computer to type out her lessons, and to present her lessons. She also was only able to vocalize learners using technology as their devices, whether those were cellphones or computers and was unable to list any applications that could aid learners with their conceptual understanding in a way that a teacher in the 'Advancing' level would be able to.

This is a problem when it comes to technology in the mathematics classroom as, when it is being used as only a form of instruction, it is not facilitating mathematics learning (Wiest, 2001). This also means that it is not helping to develop the strands of mathematical proficiency as, when teachers are only using it for delivery and instruction, learners are not being given an opportunity to develop conceptual understanding, meaning that the technology is not helping to improve our mathematics grades (Rakes et al., 2020).

Rose was in a similar position and defined technology as:

> *Rose: I think of computers, I think of kids having access to the internet. I think of all of the lessons that I have to set up and ways to make it interesting on the computer.* (Rose Interview; lines 10-11)

Interestingly, Myrtle was able to see past technology as just a device, and even recognized her own short fallings before engaging in her teaching qualification.

> *Myrtle: Before this year I would have thought very much technology as a device, like using computers or phones or things that are only simulations and things that are only available … I have opened up my definition a little bit to include various strategies of things that I would never have encountered before.* (Myrtle Interview; lines 30-37)

However, in her lesson, she did not demonstrate this and used technology for her own presentation and did not allow learner use. It would be very interesting to see how else Myrtle uses technology in her lessons as her understanding of incorporating technology into teaching demonstrates a deeper understanding of the role it plays and how it can be used than just having a device in the classroom.

At the level of 'Recognising', the teachers are really only using technology as a form of motivation. Rose and Myrtle both express this. This can be seen as a positive as the motivational use of technology can help to develop learners' productive disposition towards mathematics; however, if teachers were able to use technology in an Advancing level, it would offer opportunities for learners to build connections and develop their conceptual understanding within mathematical proficiency (Rakes et al., 2020). Myrtle is aware of this even if she is not exhibiting it within her lessons.

> *Myrtle: I think that would deepen an understanding rather than just rote learning.* (Myrtle Interview; line 66)

Until these teachers are able to conceptualize technology as something that allows them to create situations for learners to develop their conceptual understanding, and not just the vehicle being used to teach, they will not be able to meet the 'Advancing' level, and develop their TPACK fully, and in turn teach that mathematical proficiency which will raise our Grade 9 benchmark score overall in the TIMSS results.

4.4.2 Knowledge of students' understandings, thinking, and learning of mathematics with technology

This knowledge area looks at the knowledge a teacher has around their learners and how the learners can learn mathematics with technology; they also believe that technologies are very useful tools to help learners with mathematics (Niess, 2007). At level 5 of this knowledge domain, teachers use technology to develop higher order thinking skills in learners which, in turn, leads to a deep understanding of the subject (Kaplon-schilis & Lyublinskaya, 2018) which helps to promote mathematical proficiency.

Both Daisy and Rose scored an outright level 1 for this domain; however Myrtle interestingly scored a 2 for the teacher criterion and a 1 for the learner criterion. Myrtle was able to use technology herself in a teacher-led format, but still appears to be struggling to allow the learners to use the technology. This is perhaps because Myrtle is retaining full control of her classroom and is leading the instruction. Her role appears to be to deliver material to her learners and she is able to use technology to do this. Myrtle seems to be a confident teacher in Quadrant D of Tarling and Ng'ambi's Teacher Change Frame. She is confident in utilizing technology to present material to the learners but isn't able to use it to allow learners access to more transformative pedagogies (Tarling & Ng'ambi, 2016). Unless Myrtle is able to move out of this quadrant and use technologies so that they are not just for teacher-led instruction, its use won't facilitate learning (Wiest, 2001), and promote mathematical proficiency. This means that it will not improve the South African TIMSS benchmark scores.

When it comes to knowledge of students, it is important for a teacher like Myrtle to consider her learners' knowledge and ways of thinking (Kilpatrick, Swafford & Findell, 2001) and then look at ways of using technology to create an environment that allows each learner to take mathematical action and see immediate consequences (Kaplon-schilis & Lyublinskaya, 2018).

Cognitively, Myrtle understands this and is able to vocalize this and understands that a teacher's role is to have a general knowledge about their learners' thinking, especially tied to their age, and backgrounds (Kilpatrick, Swafford & Findell, 2001).

Myrtle: I think for me it is a big thing on exploration, investigation and imagination. I think that if learners get to see things on their own and build connections or make connections on their own, that their learning will be deeper and my teaching can be enhanced. So for instance, we have to look at what learners are doing in their real lives. (Myrtle Interview; lines 116-120)

She goes further on to explain how teachers can use applications that learners are using in their day-to-day lives like Tik Tok and apply those to mathematical concepts. If Myrtle were doing something like this, she would be integrating each of the strands of mathematical proficiency, and, in turn, achieving a level 5 of 'advancing'.

Rose displayed strong knowledge about how important it is to know about your learners when working with mathematics. She sees an important part of her lesson being making sure that she knows her learners' circumstances and what they are bringing into the classroom. She has found a way of using technology to do this and enjoys using Peardeck's integrated questions to learn more.

Rose: Already you get, okay so it is not about the maths itself maybe it is about something that happened at home or something somebody said or you're struggling with one sum. You got all the other stuff ... now you're struggling and now your brain just switches off. I'm not clever because I don't know how to do this simple sum. (Rose Interview; lines 191-194)

Daisy also can vocalize how important it is to create an environment that has learners use the technology to be able to have an action on the material and learn from the consequences (Kaplon-schilis & Lyublinskaya, 2018).

Daisy: That the technology learners according to the new generation, they like to play. Maths is based on practice but if they practice the mathematical skills by doing that, they will practice in such a way that by the time they are doing that they using technology they will feel as if they are playing whereas they can learn at the same time. (Daisy Interview; lines 233-236)

However, she also is not clear on how learners need to be using technology to do more than just practice the content that they have learnt, and engage in more than just procedural fluency. The above does show a slight tendency to want to use technology to create more of a productive disposition towards mathematics – an important strand within mathematical proficiency.

Rose also demonstrated how TPACK can help to both develop mathematical proficiency in learners, and help teachers teach mathematical proficiency. When asked what she sees as the purpose of technology in the mathematics classroom, she immediately looks at how it can create more of a productive disposition towards mathematics.

> *Rose: Because kids are so used to just working out of the textbooks. Yes you do your examples on the board but when you do a 3d thing on the board, you can have the shape there but at a certain age the kids are just switched off. But as soon as that screen opens up that kid is excited because they can come and turn that 2d thing on the board is now capable of moving.* (Rose Interview; lines 36-39)

But what is also tied in with this is that through the use of the technology being able to shift a shape between 2d and 3d, learners are able to build on both their strategic competence, and adaptive reasoning, meaning that a teacher who has TPACK and uses technology in the classroom is able to integrate more of the strands to develop mathematical proficiency.

When it comes to being able to teach to develop mathematical proficiency, too many teachers view mathematics as a set of facts and procedures that learners need to be able to produce by memory, and this can be seen in their instruction (Kilpatrick, Swafford & Findell, 2001). This is seen very clearly with Daisy in her classroom where she engaged in choral response with her learners. She uses the projector to allow learners to read off of it and drills them on definitions and answers.

Even though Daisy's learners appear to only be using technology as a form of drill and practice, she does seem to have an understanding that the technology needs to have an immediate effect and consequence for the learner and how the teacher's role turns more to guidance.

> *Daisy: They're doing it to do the calculations. They are using it to do their calculations then to check sometimes what I like about the computers [is] sometimes the computers can tell them that whether they are right or wrong.* (Daisy Interview; lines 188-191)

The proper use of technology in the mathematics classroom would be use that focuses on inquiry, reasoning and engagement (Wiest, 2001). The TIMSS benchmarks list the highest as the 'advanced benchmark' and this has learners being able to apply and reason with mathematics through a variety of problems and be able to make generalizations based on this (Long & Wendt, 2019). The use of technology could elevate mathematics learners through the benchmarks and give them these abilities.

4.4.3 Knowledge of the Curriculum

This domain of knowledge focuses on the teaching knowing how to work with different technologies within the different topics and areas of the curriculum (Niess, 2007). The teachers have a clear understanding of how activities in a technology-enriched environment need to be structured and scaffolded throughout the curriculum (Niess, 2007). A teacher who has a level 5 fully developed TPACK in this area would be able to use technology to challenge the traditional mathematics curriculum and engage learners through it (Kaplon-schilis & Lyublinskaya, 2018). Learners would be using technology to engage in tasks which help them make connections between topics within, and outside, of the curriculum (Kaplon-schilis & Lyublinskaya, 2018).

None of the teachers in this study scored more than a 2 on the rubric for this domain. It was clear that this area was the weakest as they did not seem able to make sense of the idea of how technology can fit into the curriculum. During the interview process, when asked how technology can fit into the curriculum, Rose was unable to answer the question and answered honestly that she did not know. Myrtle attempted to answer the question but still seemed to be stuck on how the technology is fitted to a task, specifically mathematical investigations, and couldn't conceptualize it as a tool that changes the learning of the curriculum. Daisy continues to see technology as a physical item, for example a cellphone, and views that this is what needs to integrate into the curriculum. She sees technology integrating into the curriculum as something that can create a productive disposition in her learners as:

Daisy: They enjoy working with their cellphones. (Daisy Interview; line 199)

Shulman (1986) defined a teacher's knowledge of the curricular as understanding the alternative materials and texts available to teach the subject. He said that for a teacher to have curricular knowledge, they not only have knowledge of all of the instructional, and alternative, materials available, but also have a clear understanding of other subjects and topics that learners are engaging with (Shulman, 1986). Interestingly, Rose demonstrates an ability to do this and has been interacting with teachers in other subjects for inspiration.

Rose: The arts and culture teacher actually said this [Canva] is a nice app, they found out about this app from another school. The kids are making posters, they can create, why don't you try for EMS when you do marketing. And then I thought okay maybe I can use this for my mindmap, or they had … distinguish between the binomials, polynomials, monomials and so they had to make a poster saying that they are selling I'm presenting monomials. (Rose Interview; lines 209-215)

In Rose's description of another lesson she shows that she understands that similar technology can be used across different subjects, and also be used by the learners to make these connections.

What is very clear in the weaknesses of this area is that teachers are not really sure on how technology best fits in with their mathematics curriculum.

Myrtle: I do think that the way that I describe before I am not sure if that actually does help the curriculum. Sorry, I am still learning the curriculum can be a thing on its own. (Myrtle Interview; lines 215-216)

Myrtle acknowledges this weakness and shows a desire to learn more. For teachers to really develop their TPACK and to teach for mathematical proficiency, part of professional development undertaken really needs to look at how technology can integrate into the curriculum as a whole, and focus on links between topics and subjects.

4.4.4 Knowledge of Instructional Strategies

When a teacher has knowledge of instructional strategies, they are able to use technologies in multiple manners to meet their lesson objectives, and also the needs of their learners (Niess, 2007). Interestingly, Rose scored a 2 on the rubric for this domain of knowledge, and that was only because her use of technology with the learners was at a 1, whilst hers was at a level 3. This shows that teachers seem to be becoming more comfortable with using technologies. Considering that whether or not technologies are used in the classroom seems to be down to whether the teacher is able to use them (Thomas & Hong, 2013), it means that developing a teacher's confidence in using technologies for instruction is paramount to developing TPACK.

In order for teachers to be able to develop mathematical proficiency in their learners, they need to have knowledge of different types of tasks and tools that can teach the important mathematical concepts (Kilpatrick, Swafford & Findell, 2001). When technologies are added into this, teachers need to have experience in looking at a technology and being able to see how it could be used in their subject in different ways. Once they are able to do this, they will be exhibiting TPACK, and will be able to teach for mathematical proficiency.

Rose demonstrates a curiosity for what technologies are out there for her to use to teach mathematics. At one point in her interview when asked about different strategies she uses in her classroom, she expressed the opinion that she is tired of using YouTube videos; however, she does not seem to know of what else to use so has rather decided to start asking the learners to find different technologies that can be used in the classroom.

> *Rose: They come and they share what apps they've discovered. And like once a term they need to come to me with something new. And they can't wait. I think the whole holidays they are just searching.* (Rose Interview; lines 381-383)

Through asking this of her learners, Rose is able to start creating a community for her learners who are setting the groundwork for learning activities that can make sure that all are engaged in deep mathematical work (Kilpatrick, Swafford & Findell, 2001), which would bring them closer to achieving mathematical proficiency.

Rose appears to be exhibiting level 5 techniques of advancing in this domain area. She desires for her learners to experiment with the technology in her mathematics classroom and is using this technology so that they are able to experiment with the mathematics.

> *Rose: So, with any new concepts I try and find either a video or an interactive activity where they can come and move things or turn it around, and flip it upside down.* (Rose Interview; lines 263-264)

Rose is clearly demonstrating how Stapf & Martin (2019) said that learners need to be able to see abstract concepts as concretes ones, and the technology is what is enabling this to happen. A teacher who has developed their level 5 in instructional strategies, will be able to find multiple ways of using technology so that learners are able to experiment and facilitate the shift of these concepts in the learners' minds. Learners will be able to make sense of the mathematical content and be able to apply reasoning and justification to concepts (Kaplon-schilis & Lyublinskaya, 2018). With this, learners will be able to strongly develop their mathematical proficiency and, in turn, achieve higher scores on the TIMSS benchmark test.

Myrtle is still not able to let go of being in charge of the technology in her classroom, even it comes to instructional strategies. She recognizes that technology is able to allow situations where experimentation can help to build mathematical proficiency; however, she voices it in a way where she is the one showing the learners how experimentation on something can lead to another result.

> *Myrtle: Instead of just next, next, and next on the slideshow, we could use Geogebra to actually [show] with that sliding tool what happens when the gradient is negative.* (Myrtle Interview; lines 315-316)

Myrtle is clearly in Quadrant D of Tarling and Ng'ambi's Teacher Change Frame and feels comfortable with the use of technology. Her use of technology when it comes to instructional strategies is transmission-orientated and is restricted, with her being in control (Tarling & Ng'ambi, 2016). If she were to move away from this and allow learners more control with the technology, she would be able to build their ability to reason, justify, and make sense of the mathematical content through their own explorations. This would help move her into a

Quadrant C and use more transformative pedagogies that allow for exploration by the learner (Tarling & Ng'ambi, 2016) and the development of mathematical proficiency.

Daisy doesn't seem to understand that using technologies can transform the way that she teaches.

> *Daisy: I can find, sometimes you find that maybe if they don't understand it so you give them verbal. But immediately, press the computer and the learners they can read it. They can understand it better because it is going to explain step by step with the computer.* (Daisy Interview; lines 263-266)

She still appears to view the use of technology as modelling the same thing that she would have done without it.

Wiest (2001) looks at how using technology can help to make pedagogies used for teaching mathematics more effective. If a teacher is not able to see how the technologies can do this, it means that TPACK won't be apparent and the technology will not be used in a way which links the strands of mathematical proficiency.

4.4.5 The hidden domain of knowledge

Mishra (2019) has discussed how the outer line of the TPACK framework needs to be renamed as ConteXtual Knowledge, or XK. This knowledge is extremely important when it comes to assessing, or even working at improving, TPACK.
If teachers in South African schools are not integrating technology to improve mathematical proficiency, it becomes important for researchers, and professional development program creators, to look at these teachers' contexts, and their XK.

Rose is the teacher in this study who appears to have the most developed TPACK, even if she is not at level 5. It is important to note that whilst Rose is at a Quintile 5 South African school, the social economics of the area the school is located in means that parents are not able to contribute much to the school fees, leaving School A relatively under-funded.

Rose: I think that the department must really relook the quintiles and such. Because if you think what the quintile 5 community should be like, our kids don't have that. (Rose Interview; lines 437-439)

It becomes important to acknowledge this when assessing Rose's TPACK as she may not have the resources or the access to truly exhibit this, and her environment could be what is holding her back (Thomas & Hong, 2013). She could have a strongly developed TPACK but does not have the correct affordances and tools to demonstrate it.

Thomas & Hong (2013) see the biggest defining factor of technologies being used in the classroom as the teacher. As Tarling and Ng'ambi (2016) have shown, a teacher is more likely to use technologies when they, themselves, are comfortable in the use, and will most likely shift over to learner engagement with technology after mastering their own use. COVID-19 has created situations in South African classrooms where teachers now have to use technologies due to emergency remote teaching that has been ongoing.

Rose: But like over this last term, those 3 months, people were sharing. Okay, did you try this with your class? We use it in English but you might be able to use it for this subject. And then we will try it with our learners because a lot of us were thrown into the deep end when lockdown we had to prepare lessons just to keep the kids engaged. (Rose Interview; lines 198-201)

Rose shows that if we want to improve our Grade 9 Mathematics teachers' TPACKs, we need to be providing them with the right context to do so. A situation where they have to utilize technology means that they will need to develop this or not be able to teach their learners.

Affordances of a school are also an important area of XK. For example, if a teacher knows that learners only have access to technologies at school, then she needs to make sure that the learners have ample access to technologies at school outside of the classroom.

Myrtle: So if I do want something done using a specific digital technology, or some kind of platform, I have to give them enough time to do it during school or during break or after school in the library or whatever. (Myrtle Interview; lines 441-443)

This can create a classroom context where a teacher only uses the technology to present to learners because she knows that they will struggle to engage with technologies inside or outside of the classroom due to the school's affordances.

In conclusion …

This chapter has detailed the primary and the secondary analysis of the study's data. The primary analysis used the TPACK rubric to analyse a recorded lesson from each teacher, their lesson plans, and any lesson artifacts used by both them and the learners during the lesson. The secondary analysis used the semi-structured interview questions to delve deeper into each domain of knowledge in TPACK.

Chapter 5: Discussion and implications

5.1 Overview of the study

The focal question that this study has investigated focused around the TPACK of Grade 9 Mathematics teachers, asking *how developed* their TPACK is and how technology use should change to develop their TPACK. The central argument was that when technology is used properly in the classroom, it has the power to improve learners' mathematical proficiency and therefore it is important for our teachers to have fully developed TPACKs. This is incredibly pertinent in view of the TIMSS Mathematics results and the Department of Basic Education's performance agreement to raise the Grade 9 TIMSS result so that all learners are passing the low benchmark by 2023.

The data derived from the three participants in this case study provided insight into their TPACK and complex situations surrounding the development of their TPACK within their individual contexts. The following sections take a review of the research questions provided in Chapter 1.

5.2 How developed is the TPACK of Grade 9 Mathematics teachers?

A teacher with fully developed TPACK uses technologies in the classroom to help develop deeper conceptual understandings, assists learners to make connections through meaningful interaction with the mathematical content (Kaplon-schilis & Lyublinskaya, 2018). The teacher with TPACK has a clear understanding of how their teaching and learning changes due to the technology used (Koehler, Mishra & Cain, 2013) and they are not using technology as a form of substitution for their instructional strategies. These teachers are capable of transforming their classrooms through the integration of technologies that achieve the goals of learning in ways that were previously unattainable (Tunjera & Chigona, 2020b). The use of the TPACK SAMR model (Tunjera & Chigona, 2020b) shows that a teacher with TPACK would be engaging in transformative activities in the classroom that redefine how teaching and learning occurs. These transformative activities place teachers with TPACK in Quadrant C of the Teacher Change Frame (Tarling & Ng'ambi, 2016), meaning that the technologies would be in the hands of the learners, allowing them to use their knowledge to apply and create.

The teachers in this study did not appear to demonstrate this ability, meaning that their TPACK is underdeveloped. In the observed lessons, the technology was always in the hands of the teacher with all three teachers placing themselves squarely in Quadrant D on the Teacher Change Frame (Tarling & Ng'ambi, 2016). The learners in the classrooms of the three observed teachers were consumers of the technology used during the lessons and they were not involved in any creation or transformative activities. Both Rose and Myrtle briefly described how they could place the technology in the hands of their learners. Myrtle (see section 4.6.2) explains how she knows that learners can use technology in the mathematics classroom to build and make connections, but does not seem entirely sure how to make this happen. Rose (see section 4.6.4) expresses how she has her learners come up to the front and engage with the technology, but she isn't expressing many ways that the learners independently engage with technology and create. She is still leading the technology in the classroom.

With guidance on placing technology into the hands of the learners and further training as to how the three knowledge domains of pedagogy, content, and technology relate to one another (Harris, Koehler & Mishra, 2009), Myrtle and Rose may be able to reach the advanced level, and have developed TPACK (Niess et al., 2009). For Daisy, an intervention based specifically on identifying technologies for the mathematics classroom might be able to aid her in moving up the levels. In section 4.6.1 we see how Daisy only sees technologies as the actual hardware used in the classroom. She thinks that because her learners are using a tablet or a computer, that they are pedagogically using technology in the classroom. This places her in the substitution area with under developed TPACK.

It is, however, important to note that the ConteXtual Knowledge of the teachers also plays a role in defining their TPACK. When analysing a teacher's TPACK, a researcher needs to be cognisant of the affordances and environment of the school, the suburb, the learners' environment, and the country (Mishra, 2019). The teachers in this study have shown that context plays an important role when analysing TPACK. Rose expresses in section 4.7 how, even though her school is listed as a top quintile, the learners do not have social and economical access to technology; meaning that, even if she had fully-developed TPACK, this would not be possible to create in a resource poor classroom. As Rose shows, a teacher who appears to have poorly developed TPACK through observation in the classroom may, in fact, have developed TPACK but they just lack the resources and the access to display it in the classroom. This means that any research done into the TPACK of teachers needs to also analyse and report on environment and XK of the teacher and the school.

5.3 How should technology use change to develop TPACK?

TPACK is made up of seven different knowledge areas that intersect (Koehler, Mishra & Cain, 2013). The goal when researching teachers and their TPACK is to understand what knowledge teachers need in order to effectively be able to use technology for teaching and learning and not to be distracted by comparing the seven domains of knowledge (Saubern et al., 2020). This study focused solely on the specialised knowledge needed by teachers to best integrate content and pedagogical knowledge with their knowledge of technology – the knowledge domain of TPACK (Saubern et al., 2020). A rubric (Kaplon-schilis & Lyublinskaya, 2018) was used to analyse different knowledge domains of teacher's use of technology in regards to their overarching conception, knowledge of students, knowledge of the curriculum, and knowledge of instructional strategies (Niess, 2005). This rubric measured both how a teacher uses technology in these knowledge domains and also how a learner uses technology in the classroom.

What the study found was that these Grade 9 mathematics teachers were scoring lower in each knowledge domain on the rubric when it came to the learners' use of technology in the classroom. Rose and Daisy both scored lower on the learner-centred criteria of the rubrics. They appeared to be comfortable when it came to them using technology. In section 4.2, Rose's lesson analysis shows how she is confident in using video, and utilising a SMART board to work with geometric shapes. She is clearly functioning in a Quadrant D-style classroom where the technology emphasises the lower-order thinking skills of remembering and understanding (Tarling & Ng'ambi, 2016; Kaplon-schilis & Lyublinskaya, 2018). Her learners are invited up to the board to show that they can identify shapes and sizes, but are not creating any on their own. In section 4.3, Rose used her computer to project work, but the learners are still working in their classroom work books. During her interview in section 4.6, Daisy refers to how the learners are able to use their calculators and cellphones to check whether they are correct, but they are not utilising the technology for anything other than lower-order thinking tasks. With both Rose and Daisy, the learners' use of technology was centred around drill and practice, and did not allow space for learners to make any connections with the mathematical content (Kaplon-schilis & Lyublinskaya, 2018).

In order for these teachers to develop TPACK, they need to focus on the learner's use of technology in the classroom. This is clear as the teachers in the study scored the lowest when it came to learner use of technology. This lack of learner use of technology could be linked to a teacher's Fluency of Informational Technology (FITness) and their deeper understanding of technology as opposed to their general computer skills (Koehler, Mishra & Cain, 2013). The three teachers in this study appear to be comfortable with the use of technology in their work and personal lives, but lack an understanding of how technology can aid higher order thinking skills or evaluation, creation, and analysis amongst their learners (Tarling & Ng'ambi, 2016; Kaplon-schilis & Lyublinskaya, 2018). The teachers lack a FITness when it comes to technological knowledge. Rose uses the technologies as a way of presenting teaching and learning material to the learners, and Daisy refers to technology as way of reinforcing understanding and practicing. Myrtle could possibly be the closest when it comes to FITness as in section 4.6.2, she refers to how learners need to use technology in order to explore, investigate and imagine.

It is important to note that this lack of FITness may also be due to the ConteXtual Knowledge of these teachers. It is entirely possible that the reason why technology is not being placed in the hands of the learners and teachers are practicing in Quadrant D is because of a lack of resources and access. Rose exhibited more FITness in her interview and she was able to vocalise not only how learners could use technology, but also elaborate on the benefits of learners using technology in the classroom, but she does not have access to the technology to do this. FITness can appear to not be developed, so it becomes important to probe the teacher's classroom and environment before assessing this.

5.4 How can TPACK help to develop mathematical proficiency?

In the past, procedural skill, or learners' ability to memorise and do algorithms, was seen to be mathematical proficiency (Groth, 2017); however in 2001, Kilpatrick defined mathematical proficiency (MP) and power as a learner's ability to reason, solve problems, connect mathematical ideas, and communicate this to others in the classroom (Kilpatrick, Swafford & Findell, 2001; Groth, 2017)

The strands of mathematical proficiency are:

- conceptual understanding—comprehension of mathematical concepts, operations, and relations
- procedural fluency—skill in carrying out procedures flexibly, accurately, efficiently, and appropriately
- strategic competence—ability to formulate, represent, and solve mathematical problems
- adaptive reasoning—capacity for logical thought, reflection, explanation, and justification
- productive disposition—habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's own efficacy. (Kilpatrick, Swafford & Findell, 2001: 116)

If all five strands of MP are interwoven and being met, a learner is said to have mathematical proficiency and it is the teacher's responsibility to create a classroom where this can occur (Groves & Susie, 2012). TPACK is a form of knowledge that can assist a teacher in providing this environment.

A teacher with TPACK is able to transform their classroom and shift the work being done into transformative pedagogies that deal with higher-order thinking (Tarling & Ng'ambi, 2016; Tunjera & Chigona, 2020b). When a classroom has shifted into a Quadrant C classroom that places the technology in the hands of the learner and transforms the learning, learners move from consuming content to being active creators through the use of technologies (Tarling & Ng'ambi, 2016). A teacher who has reached level 5 on all forms of knowledge on the TPACK rubric has a classroom that allows learners to engage in all of strands of mathematical proficiency.

A score of level 5 in the overarching conception means that teachers have created a classroom using technology where they give learners opportunities to develop a deep conceptual understanding of mathematical knowledge along with technology based learner tasks that use and develop their strategic knowledge (Kaplon-schilis & Lyublinskaya, 2018).

When a teacher scores level 5 in knowledge of students, they are yet again creating a classroom that uses technology as a tool to aid learners in developing a deep conceptual understanding of the mathematical knowledge (Kaplon-schilis & Lyublinskaya, 2018). Technology use in this knowledge domain means that learners are able to make appropriate decisions of action that lead to meaningful consequences (Kaplon-schilis & Lyublinskaya, 2018). These actions show strong procedural fluency, but also productive disposition as learners are working in an environment and with technology tools that afford them to see how useful mathematics is through these meaningful actions.

A teacher who scores a level 5 on knowledge of the curriculum is able to create a classroom that uses technology so that learners are able to make connections and create a deeper conceptual understanding of mathematical concepts throughout the entire curriculum (Kaplon-schilis & Lyublinskaya, 2018).

Finally, when a teacher has a score of level 5 under knowledge of instructional strategies, they are able to create a classroom where learners use technology so that learner reflection is promoted, along with learners being able to engage in reasoning and justification in regards to mathematical content (Kaplon-schilis & Lyublinskaya, 2018). When learners are doing this, they are engaging in adaptive reasoning.

If pre-service mathematics teacher training and teacher professional development placed an emphasis on equipping teachers with skills that help them move towards level 5 and be advancing in these forms of TPACK knowledge, it is possible that teachers will be able to create classrooms where learners will be able to develop all five strands of MP.

5.5 Validity and trustworthiness of research

Research is seen as credible and trustworthy if a research considers and avoids any threats to validity (Robson, 2002). This study has used Maxwell's (1992) typographies of validity: descriptive, interpretive, and theoretical validity. The researcher has considered and addressed these threats accordingly in regards to this study.

5.5.1 Descriptive validity

Researchers need to consider the factual accuracy of the account in their study (Maxwell, 1992). This means that descriptive validity refers to a researcher's descriptive analysis of the observed events and situations. A researcher needs to be conscious of not distorting the descriptions of what they heard and saw (Maxwell, 1992) . The researcher made sure to take notes as and when they were in the schools so that they were not relying on memory; and interviews were recorded and saved on the Cloud. Numerous cross-checks were done on the transcriptions to make sure that accuracy was kept and that reduced the threat on descriptive validity.

5.5.2 Interpretive validity

When a researcher is able to fully suspend their own beliefs and perspectives in order to successfully search for the meanings and interpretations that the participants in a study attach, themselves, to objects, behaviours, and events, then interpretive validity has been achieved (Maxwell, 1992). It means that a researcher needs to be able to critically engage in self-reflection, and acknowledge how their own perspectives and assumptions may influence the data of the study (Maxwell, 1992).

This idea of interpretive validity became very important in this research as the framework made use of Lyublinkskaya and Tournaki's (2018) TPACK rubric. When analysing the types of data that were gathered through a rubric, it is important to maintain the concept of realism and to acknowledge that any theory, concept, or finding is grounded in the researcher and participants values and perspectives (Altheide & Johnson, 1994). This means that any knowledge can be considered as contextual and other perspectives are possible (Altheide & Johnson, 1994).

The researcher critically reflected at various points of the analysis that might influence the interpretation of the rubric: the researcher's experience with using technology in the classroom, the experience they have with training teachers to use technology in the classroom, their professional background as a teacher, and the conversations that they had in passing with the teachers. These influences were able to enhance and not detract from the analysis, as they assisted in being able to read nuances in a teacher's practice in relation to the criterion in the rubric.

It is important to note under interpretive validity that this interpretation of Lyublinskaya and Tournaki's descriptions in the teacher's lesson may differ from another perspective. As Maxwell (1992) says, it is entirely possible for there to be different but equally valid accounts from differing perspectives.

Considering cautions from Maxwell, the researcher made as much effort as possible to identify any presuppositions and perceptions and avoid these. They made sure to only interpret the participants' explanations, answers, and views, and make sure that inferences that the researcher made were based on their words, without imposing any form of preconceived ideas onto the meanings.

5.5.3 Theoretical validity

Theoretical validity looks at "an account's validity as a theory of some phenomenon" and examines its legitimacy through which the theory or concept was applied and if an "agreement can be reached about what the facts are" (Maxwell, 1992). This means that theoretical validity needs to be looked at in two ways: the validity of the concepts as they are applied to the phenomenon, and then the validity of the relationships within the concept. It is important to examine in theoretical validity if the community of researchers engaging in this topic have consensus on terms used to describe phenomenon (Maxwell, 1992).

This study used criterion based on Lyublinkskaya and Tournaki's (2018) TPACK rubric and it was these domains of knowledge and criterion that were being analysing. This rubric was chosen as it has been tested for reliability and validity in previous studies, and it provided a structure for analysing TPACK specifically, so that the researcher was not distracted by the other domains of knowledge surrounding TPACK (Saubern et al., 2020).

The rubric itself has gone through rigorous testing for validity and reliability. The revised TPACK Levels rubric (version 2.0) used in this study was tested against 394 lesson plans that were developed by pre-service teachers who were enrolled in an education graduate program at a New York City university over 10 semesters. Threats to theoretical validity were reduced as other theories on measuring TPACK were considered and alternatives evaluated through the literature review, with Lyublinkskaya and Tournaki's rubric considered best suited for the study.

5.6 Implications of the study

This study supports the claims made by researchers that mathematics teachers who have underdeveloped TPACK are not using technology effectively in the classroom. It adds to the discourse by showing that, whilst these three teachers may be becoming more comfortable in using technology in the classroom, they have not been equipped with the knowledge domains necessary to develop their TPACK.

If the Minister of Education wishes to succeed in improving the TIMSS results so that all Grade 9 learners are scoring above the low benchmark, it is important that mathematical proficiency is being taught in classrooms. This study has looked at how TPACK can create the knowledge base that teachers need in order to do this, and this means that improving our Grade 9 Mathematics teachers' TPACK should become of utmost importance.

A study focused solely on the ConteXtual Knowledge of Grade 9 Mathematics teachers may spread further light on the true level of TPACK within teachers in South African schools, as it could very well be each individual teacher and schools context that is creating a situation where teachers are not able to move forward or develop these domains of knowledge. COVID-19 and the contexts that it has brought to South African teachers and classrooms have shown that teachers are able to push themselves further along the levels of TPACK, and it is important to see how remote emergency teaching is helping to develop their TPACK even further.

5.7 Limitations of the study

The analysis of the participants' lesson recording and lesson artifacts informed their TPACK results; but it is important to note that these lessons were only a snapshot of an entire year's worth of teaching. Whilst the rubric is capable of measuring the TPACK exhibited in the lesson, it does not take into account what could be occurring in other lessons, and whether or not the teacher in fact demonstrates TPACK when engaging with different content.

When engaging in an interpretive study, one needs to acknowledge that texts – the researcher is defining the data derived as a text – are always partial and always incomplete (Lincoln, 1995). Because of this, the study cannot categorically state that these results are a true reflection of the teachers' TPACK.

Saal, Graham, and Rynveld (2020) looked at how teachers in South African schools are not integrating technologies in a manner that promotes meaningful learning, and were mostly using these to substitute for their regular teaching style. This study states that meaningful learning would be mathematical proficiency and the results reinforce this claim from the analysed lessons, but this was only one lesson. It would be interesting to delve further into teachers' lessons over a longer period of time to see if TPACK is occurring in any other lessons.

Further research in a longitudinal study of a wider selection of Grade 9 mathematics teachers may indicate a more close reflection of the teachers' TPACK, considering their contextual situations.

5.8 Conclusion

In closing, this study has revealed the importance of developing specific areas of knowledge within teachers in order to develop their TPACK. Through the results of these three teachers across different schools in the Western Cape, it does not appear that the Grade 9 mathematics teachers have fully developed TPACKs. The teachers recognize the need for technology in the mathematics classroom, but need assistance in how to implement it in a learner-centred manner that helps to develop mathematical proficiency. Because the data sample was small, it is not possible to conclusively say that this would reflect on all Grade 9 mathematics teachers and it would be necessary to engage in a study with a larger sample size.

The teachers in this study show that, for them, integration of technology into the curriculum is an area of TPACK that needs to be improved. Further research would show if this area needs improvement across more Grade 9 mathematics teachers. This is important for any professional development courses aimed at Grade 9 mathematics teachers as these could need to have a focus on integration technology across the curriculum in order to assist in creating classrooms that foster mathematical proficiency amongst learners.

The results of the study show that these three teachers do not appear to be ready to place the technology in the hands of the learner. A teacher who has appropriate knowledge to teach mathematical proficiency would have developed TPACK, and, as Kaplon-schilis & Lyublinskaya's rubric has shown, need to be advanced in both teacher-led use of technology, and learner-led use of technology. The teachers in this study showed a clear indication to use technology as instruction-led, or Quadrant D (Tarling & Ng'ambi, 2016). More opportunities to help mathematics teachers move into more transformative pedagogies, where the technology is in the hands of the learners, need to be developed in order for mathematical proficiency to be developed amongst Grade 9 learners to reach that TIMSS benchmark.

However, ConteXtual Knowledge could be the reasons for the findings amongst these three Grade 9 teachers. A teacher and their school's environment play a role in whether a teacher is able to engage with the TPACK that they potential have. This study has shown that when one of these teachers needed to utilize technology during the COVID-19 pandemic, they were able to engage in learner-centred transformative pedagogies. It would be of interest in further research to see the effects of COVID-19 on teachers' TPACK when the context placed the teachers in an environment where technology for teaching and learning was essential.

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Appendix

The data for this research is extremely large so the researcher has chosen to leave links to the data that is in Cloud Storage.

Teacher A: Rose - https://tinyurl.com/TeacherARose

1. Rose Recorded Interview
2. Rose Recorded lesson
3. Rose lesson plan
4. Rose lesson artifacts

Teacher B: Daisy - https://tinyurl.com/TeacherBDaisy

1. Daisy Recorded Interview
2. Daisy Recorded lesson
3. Daisy lesson plan
4. Daisy lesson artifacts

Teacher C: Myrtle - https://tinyurl.com/TeacherCMyrtle

1. Myrtle Recorded Interview
2. Myrtle Recorded lesson
3. Myrtle lesson plan
4. Myrtle lesson artifacts

Semi-structured interview questions - https://tinyurl.com/TPACKQuestions