# THE INTEGRATION OF GEOGEBRA SOFTWARE IN THE TEACHING OF MATHEMATICS IN SOUTH AFRICAN HIGH SCHOOLS

**by**

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# DECLARATION

I hereby declare that **"The integration of GeoGebra software in the teaching of mathematics in South African high schools"** is the result of my own investigation and that all sources I have used or quoted have been acknowledged by means of complete references. I further declare that the work is submitted for the first time at this university towards a PhD in Education degree and it has never been submitted to any other university for the purpose of obtaining a degree.

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LG MOKOTJO

June 2020

# DEDICATION

**to**

**my late grandmother, Julia Babhekile “JB” Molepo**

**and**

**my late grandmother, Letta Ntombizini Sibeko**

Neither of them could read or write but they instilled in me the love and value of education. Their wisdom, courage, tireless hard work and love inspired me to always strive to do my best in life. I hope this inspires all those women who, in spite of their abilities, are deprived of pursuing their dreams due to circumstances that their obstinate determination should never abate.

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# LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ATP | Annual Teaching Plan |
| CAPS | Curriculum and Assessment Policy statement |
| CAS | Computer Algebra System |
| CCSSI | Common Core State Standards Initiative |
| CK | Content Knowledge |
| DBE | Department of Basic Education |
| FET | Further Education and Training |
| GET | General Education and Training |
| ICT | Information and Communication Technology |
| ICT4RED | ICT for Rural Education Development |
| ISPFTED | Integrated Strategic Planning Framework for Teacher Education and Development in South Africa |
| IT | Information Technology |
| PCK | Pedagogical Content Knowledge |
| PD | Professional Development |
| PCK | Pedagogical Content Knowledge |
| PGCE | Postgraduate Certificate in Education |
| TCK | Technological Content Knowledge |
| TK | Technological Knowledge |
| TIMSS | Trends in International Mathematics and Science Study |
| TPACK | Technological Pedagogical Content Knowledge |
| TPK | Technological Pedagogical Knowledge |

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# SUMMARY OF THE STUDY

Mathematics achievement is known to be the pillar of a prospering society because of the critical and analytical skills it imparts to those who excel in it. South Africa is rated among the worst-performing countries internationally with the worst performance on high school level. Poor performance in mathematics is a global phenomenon and better performing countries have resorted to the integration of information and communication technology software as being one of the solutions to the problem. In South Africa, the issue of poor performance is acknowledged and various intervention strategies for improving mathematics performance have been implemented. Such initiatives include, among other things, lesson study, the use of manipulatives and the integration of technology. However, the *Second Information and Technology in Education Study 2006* report, which probed the pedagogical use of information and communication technology across the world, found that South Africa was lagging behind in the integration of technology, although most South African schools had access to computers and the Internet. There is a widespread phenomenon of training teachers in the integration of information and communication technology and, particularly, GeoGebra software in the teaching of mathematics in South African high schools.

Using technological pedagogical content knowledge as a lens, this qualitative study used semi-structured interviews, non-participant observations and document analysis to collect the necessary data. The data were collected from four purposively selected high school mathematics teachers from three different schools in the North-West Province. The key finding from this study was that teachers perceived GeoGebra as a valuable tool in the teaching of high school mathematics within the South African context, despite the challenge that it was time consuming to prepare for a lesson incorporating GeoGebra. They found GeoGebra useful in creating a fun learning environment while allowing learners to visualise and conceptualise the abstract concepts in mathematics. Furthermore, the study established that teachers had limited knowledge of GeoGebra features and lacked pedagogical content knowledge in terms of their practices in teaching with GeoGebra.

The study concludes that the integration of GeoGebra and any other mathematics software or hardware does not happen in isolation to the social factors that affect the learning environment. Furthermore, the study concludes that professional development of teachers in the integration of GeoGebra is not conducted in a manner specified in the *Guidelines for Teacher Training and Professional Development in ICT* (DBE, 2007). Therefore, this study recommends the enhancement of professional development with a focus on GeoGebra because of its strong link to the South African curriculum. Professional development takes strong measure in securing information and communication technology tools for learners to gain practical experience of learning with technology.

**Keywords:** Information and Communication Technology, Information and Communication Technology Integration, Teacher Practices, GeoGebra Software

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# CHAPTER 1: ORIENTATION AND BACKGROUND OF THE STUDY

## 1.1 Introduction

This study sought to explore how teachers integrate GeoGebra software in the teaching of mathematics in South African high schools. The integration of information and communication technology (ICT) is hailed as part of the solution in transforming mathematics education globally. The study makes a distinction between ICT in terms of its hardware components and software application. GeoGebra is one of the respected mathematics software applications in the teaching of mathematics in developed and developing countries. In South Africa, in particular, widespread training sessions have been conducted in various provinces, where teachers have been exposed to the integration of GeoGebra. Consequently, most teachers in South African high schools use GeoGebra in teaching mathematics.

This study explores teachers' perspectives and experiences in the integration of GeoGebra in the teaching of mathematics within the South African curriculum. It further explores their knowledge of ICT tools and their exposure to professional development (PD) and support for the integration of GeoGebra.

Aspects that are presented in this chapter are background information of the study, the problem statement, the research questions, the research aims and objectives, the significance of the study, the delimitations of the study and, lastly, the clarification of terms.

## 1.2 Background of the study

Mathematics achievement is known to be the pillar of a prospering society because of the critical, analytical and problem-solving skills that it imparts on those who have studied it (Fatima, 2013; Suratno, 2016). In the international community, mathematics is one of the subjects that determines the health of a country's education system (Reddy et al., 2015). Mathematics is also known to enhance people's everyday lives and, consequently, individuals who struggle with mathematics tend to be disadvantaged in the large-scale economic upsurge of any country (García-Santillán et al., 2016) The success of a country's economy is linked to its success rate in mathematics (Kadosh et al., 2013). In acknowledgement of the value of mathematics, the National Development Plan (2012) of the South African government stipulates that mathematics education is a priority in South Africa. Hence, the plan includes increasing the number of students who are eligible to study mathematics and science degrees at the universities. The present era requires mathematics knowledge that includes digital technology in various contexts. Mathematics thinking and problem-solving skills are needed to analyse information and solve problems, make sound financial decisions and enhance people's quality of life in general (Forgazs et al., 2010).

On the other hand, mathematics is renowned for being one of the most challenging subjects. Most learners feel that mathematics involves concepts and proofs that are abstract and difficult to understand. Learners fail to develop the crucial visualisation and exploration skills required for mathematics (Kumar & Kumaresan, 2008; Okafor & Anaduaka, 2013). Different countries have cited different reasons as contributing factors to challenges in mathematics performance.

In Australia, the unsatisfactory performance in mathematics is linked to socio-economic factors, among other reasons. Other countries, such as the United States of America, Mexico and the countries making up the United Kingdom, attribute mathematics challenges to teachers' lack of content knowledge (CK) and curriculum knowledge (Kumar & Kumaresan, 2008).

Mathematics performance is also a challenge in South Africa, with mathematics performance at high school level being the worst of all the academic phases (Foy, Arora & Stanco, 2013). According to Reddy et al. (2015), in the Trends in International Mathematics and Science Study (TIMSS), which is a mathematics assessment written by South African high school learners in Grade 9, South Africa lies at the bottom, internationally, in terms of mathematics performance. The Annual National Assessment results also indicate that only 14% of Grade 9 learners achieve more than a 50%-mark pass (Department of Basic Education [DBE], 2014). Adler (2017) postulates that a high number of Grade 10 mathematics learners are underprepared for mathematics at that level, and it gets only more difficult for these learners as they progress in their grades to Grade 12. According to Spaull (2013), the Centre for Development and Enterprise indicates that in matric, only 6% of learners are able to achieve over 60% in the mathematics final examination. Various factors, ranging from social and academic to economic, contribute towards the poor performance in mathematics in South Africa. Ndlovu and Lawrence (2012) are of the opinion that there is a link between poor performance in mathematics and the lack or insufficient use of mathematics instructional resources in South African schools. Teachers find the integration of technology challenging, specifically in subjects such as mathematics (Buabeng-Andoh, 2012; Kramarski & Michalsky, 2010).

The value of mathematics in society cannot be ignored and, therefore, the high failure rate in this subject needs to be addressed. Kadosh et al. (2013) postulate that "poor numeracy skills have an adverse impact on the employment prospects and eventual physical health and wealth of individuals". Various intervention strategies have been suggested, which include lesson study (Doig & Groves, 2011), the use of manipulatives (Maboya, 2014) and the integration of technology (Jankvist & Misfeldt, 2015; Lavicza, 2007; Zindi & Ruparanganda, 2011).

The modern-day society uses technology in various aspects of life and, therefore, the integration of technology as one of the means of dealing with the challenges in mathematics performance should be a generally accepted method. Various studies (Chigona et al., 2010; Leendertz et al., 2013) focus on the integration of technology as part of the solution in addressing mathematics teaching and learning. The use of technology in a mathematics classroom is known to increase the engagement between the teacher and the learner (Watson, 2015), leading to increased attention, motivation and concentration (Bester & Brand, 2013) and, most importantly, higher achievement and performance (Engel & Green, 2011; Lan, 2018). The South African National Development Plan also prescribes the inclusion of quality technology to enhance the classroom experience of both teachers and learners. This encapsulates the confidence placed in the integration of technology as a means through which mathematics education can be improved (National Development Plan, 2012). However, Johnson et al. (2016) are of the view that from the acquisition of new technologies to use in the classroom to the adaptation of the curricula and teaching strategies, the integration of technology presents a considerable challenge to teachers at each school level. Buabeng-Andoh (2012) and Kramarski et al. (2010) further attest to the fact that teachers find the integration of technology challenging, specifically in subjects such as mathematics.

Most studies focus on the integration of ICT, in general, as part of an intervention strategy. However, this study acknowledges that ICT is also divided into hardware and software. Leendertz et al. (2013) propose that the integration of technology through the use of the correct ICT software is known to create an effective teaching and learning environment. It is for this reason that the focus of this study will be on the GeoGebra software because it is the mathematics software that is actually being used to communicate concepts during teaching and learning. It is worth noting that the United States of America, the United Kingdom, Denmark, Hungary and Australia are some of the countries that advocate for the use of ICT software in the teaching of mathematics. They believe that mathematics software is a means of improving the quality of the mathematics output as well as increasing the interest in mathematics and other subjects that relate to it (Jankvist et al., 2015; Lavicza, 2007). The ranking of these countries in the world can be attributed mainly to their inclusion of ICT in teaching mathematics.

Mathematics software programs are further known to bring about advantages that allow teachers to focus on specific mathematics topics, bring about dynamic movement, sound and graphics to enhance learning, and make a contribution to problem-solving tasks, practising number skills and exploring patterns and relationships (Sivakova et al., 2017). These aspects of mathematics assist learners with conceptualising the abstract ideas in mathematics and, thus, enhance their learning.

GeoGebra is widely used in South African high schools with most research showing its use in KwaZulu-Natal, Limpopo, Gauteng and Limpopo (Bayaga et al., 2019; Chimuka, 2017). Furthermore, Stols and Kriek (2012) are of the opinion that the integration of mathematics software depends on teachers' knowledge and belief about the software of choice. This study focuses on the integration of mathematics software, and specifically GeoGebra software, in a South African high school curriculum context. As participants, the study uses teachers from the North-West Province who have received training in the integration of GeoGebra software in the teaching of mathematics.

Most South African schools have access to ICT tools and various mathematics software programmes (Ford & Botha, 2014; Van Wyk, 2014). High schools in the

North-West Province of South Africa have opted to use GeoGebra as their ICT software tool of choice in teaching mathematics.

GeoGebra is a free mathematics software program that can be used for teaching statistics and probability, geometry and functions, and can be applied at different school levels. It has received numerous awards since 2002 (Hohenwarter & Lavicza, 2009; Majerek, 2014; Zilinskiene, 2014:73). The name “GeoGebra” is a combination of “geometry” and “algebra”. This software tool is known to be innovative, open-code mathematics software (GNU General Public License) that can be downloaded free of charge from the www.GeoGebra.org website. GeoGebra works on a wide spectrum of operating system platforms that have had the Java virtual machine installed (Dikovic, 2009).

In the traditional setting of teaching mathematics, learners would not regard themselves as active participants in the learning process but rather as “passive recipients of a body of knowledge” (Kumar & Kumaresan, 2008:377), focusing on definitions, rules and algorithms. In the modern setup, access to mathematics software offers teaching strategies that promote an active participation approach to learning. GeoGebra is used mainly for demonstration, exploration and modelling, creation and experimental work (Zilinskiene, 2014). It is also well respected for its impact on visual reasoning in mathematics education that makes abstract concepts meaningful (Jezdimirović, 2014).

The purpose of this study is to establish how teachers integrate GeoGebra software in the teaching of mathematics in high schools. In their research, Aydos (2015) and Chimuka (2017) conclude that students who have been taught through the integration of GeoGebra perform better than those who have been taught through the “talk-and-chalk method”. Mosia (2016) and Bayaga et al. (2019) also advocate for the integration of GeoGebra in teaching Euclidean geometry mathematics. Barve and Barve (2012) further attest that GeoGebra helps to make connections between algebra and geometry quicker and, thus, easier.

This study focuses on how teachers integrate GeoGebra software in the teaching of mathematics at high schools in South Africa. The main reason for this focus is that teachers are important in delivering the curriculum and instrumental in improving the state of mathematics education; thus, their experiences, views and challenges and how they manage are worth noting (Xu, 2017:4). This study will also focus on high school mathematics because high school mathematics is the final phase where learners can choose to pursue mathematics and, consequently, finish Grade 12 in preparation for college or university education. However, there are two higher phases within the high school level in South Africa, namely General Education and Training (GET) and Further Education and Training (FET). The study will focus in particular on the FET Phase (Grade 10 to 12). The mathematics assessment of the final year of schooling called “matric” in South Africa is based on mathematics work covered from Grade 10 to Grade 12. Jojo (2012) has noted that poor performance in mathematics in South African schools is reflected in each phase.

The various intervention strategies for teaching mathematics that exclude technology or any specific mathematics software does not seem to have caused a positive shift in mathematics performance. Therefore I hold the view that the effective integration of mathematics software, GeoGebra in particular, in teaching mathematics at high school level can serve as a platform from which changes to the curriculum can transpire with the view of obtaining better output.

High schools in North-West have been provided with training in the integration of GeoGebra in teaching mathematics. However, despite such efforts of empowering teachers in using GeoGebra in the teaching of mathematics, teachers seem to have challenges with the actual integration of technology in their mathematics teaching and learning. Van Wyk (2014) is of the opinion that most schools in South Africa have ICT resources; however, these resources are mostly either underutilised or abandoned completely. Ford and Botha *(*2014) further note that less than 10% of computer laboratories at schools are used as a part of teaching and learning. These assertions indicate that, despite the policies and the provision of ICT resources at schools for the integration of technology, there is still a gap in how teachers integrate the GeoGebra software in the teaching of mathematics at high schools

## 1.3 Problem statement

The increase in concern over mathematics performance in general and glaringly poor performance in high school call for change in how mathematics is being taught. More research has focused on the impact of using ICT without actually focusing on the integration of specific ICT software tools. Various studies have shown the benefits of using GeoGebra in teaching mathematics.

There is growing concern over South African learners' performance in mathematics. The *Global Competitiveness Report* (2013) indicates that there is a crisis in mathematics learning in South Africa. According to Reddy and Janse van Rensburg (2011), performance in mathematics in South African high schools is one of the worst internationally. Mathematics performance in a typical South African high school is average 30 to 40% per grade. The Centre for Development and Enterprise states that 90% of high school graduates in South Africa fail to meet the minimum performance levels required by tertiary institutions (Spaull, 2013). There is also concern that learners enter tertiary institutes with limited mathematics knowledge; hence the decline in mathematics-related courses. Prew (2013) indicates that the 2012 South African matriculation results reveal that only 6% of learners received more than 60% in mathematics. It was also revealed that the number of learners taking mathematics has decreased by 25% from 2008 to 2011.

Kadosh et al. (2013) state that mathematics occupies an integral position in our society. This position includes the diverse skills in employment that drive the wealth of individuals and influence career choices. The success of the economy of a country is linked to its success rate in mathematics. Therefore, there is a need to explore good teaching and learning instructional strategies that could be necessary to improve learners' achievement in mathematics with the view to improve the economy of the country. One such strategy is the use of technology in the teaching and learning of mathematics.

Technology is now regarded as one of the teaching tools that are key to enhancing the teaching and learning of mathematics (Azlim et al., 2015). Improvement has specifically been noted when GeoGebra software is used (Aydos, 2015; Barve & Barve, 2012; Chimuka, 2017). However, it remains the responsibility of the teacher to ensure that technology is adopted in the learning environment (Pedro, 2012).

Furthermore, there is also a threatening view that as much as the benefits of technology are acknowledged, the integration of technology remains a challenge for most teachers (Buabeng-Andoh, 2012). Teachers feel ready and are willing to integrate ICT tools in their teaching; however, they feel inadequately prepared for subject-specific integration of technology. They are aware of the importance of the integration of technology, but when it comes to subjects such as mathematics, they are uncertain of the relevant ICT software to use for specific topics in the subject (Kramarski et al., 2010; Meyer & Gent, 2016).

Teachers have been observed to struggle with the integration of technology despite the availability of technology resources. They are more inclined to use ICT software to teach instead of using ICT software to enhance their teaching. Teachers are noted to find it difficult to design lessons that include technology and tend to use software to teach as opposed to using it for enhancing their teaching (Banas, 2010; Tella et al., 2007). Teaching and learning would be enhanced if teachers could use ICT software programs to facilitate their teaching and utilise the program as a communication tool to augment their teaching strategies (Koehler et al., 2014). Koehler et al. (2014) concur that the integration of technology in a mathematics classroom provides learners with a better opportunity to learn in an information age. However, the actual integration of technology is a challenge for most teachers. Challenges are posed by a lack of ICT skills and pedagogical training and a lack of motivation among teachers. Ndlovu and Lawrence (2012) contend that the challenge in the integration of technology in teaching is posed by the lack of necessary skills in teaching in a manner that enhances learner performance. Banas (2010) further attests that a lack of support from teachers' managers and a lack of teacher confidence have been some of the contributing factors in challenges with regard to the integration of technology. The United Nations Educational, Scientific and Cultural Organisation (UNESCO, 2008) cautions that the accomplishment of technology-enhanced learning lies in the ability of the teacher to effectively integrate technology into classroom lessons. I, therefore, believe that teachers are critical in bringing technology into their classrooms in a manner that will benefit learners.

The integration of mathematics software signals a shift from the traditional direct-learning paradigm to learning that is focused on experiential learning. Traditional education strategies are known to attempt to teach specific knowledge to the learner directly, whereas learning by exploration focuses on stimulating the learner's initiative in gaining knowledge about a particular topic (Hoyles et al., 2013). Moreover, Hoyles and Lagrange (2010) affirm that the influences of the diverse curricula, the availability of resources in different countries, cultural diversity and issues relating to teacher beliefs and practice all shape the use of mathematics software and the impact thereof upon mathematics teaching and learning. Hence, the study focuses on the South African perspective on the integration of GeoGebra.

According to Abboud-Blanchard (2010), mathematics teachers find it difficult to integrate technology in their teaching of mathematics. Mdlongwa (2012) further attests that many South African teachers in both rural and urban schools are mystified by ICT and have only basic skills in the use of ICT. Furthermore, teachers are noted to experience pedagogical challenges in designing, ordering and organising class activities and integrating various mathematics software during teaching and learning (Leendertz et al., 2013).

Hence, the question that this study seeks to answer is: How do high school teachers integrate GeoGebra software in the teaching of mathematics in South African schools? This study seeks to reveal teaching practices for integrating technology in the teaching of high school mathematics. It unpacks the challenges experienced by teachers in integrating GeoGebra software and recommendations on how to mitigate these challenges. Several studies are focused on the integration of ICT in general and fail to engage teachers in their experience. This study makes a distinction between hardware and software in technology and focuses on GeoGebra software with specific emphasis on the South African high school curriculum.

## 1.4 Research questions

The purpose of this study is to gain insight into the practices, views and support available to teachers in the integration of GeoGebra software in the teaching of mathematics. The main research question posed in this study is as follows: **How do teachers integrate the GeoGebra software in the teaching of mathematics in South African high schools?**

In order to fully explore the posed research question above, the following critical sub-research questions will be addressed:

- What are teachers' perceptions of the integration of GeoGebra in the teaching of mathematics in South African high schools?

- What are teachers' practices in the integration of GeoGebra in the teaching of mathematics in South African high schools?
- What kind of professional development (PD) (if any) is provided to teachers in teaching mathematics using the GeoGebra software in South African high schools?
- How can we account for teachers' understanding of and practices in the integration of GeoGebra to teach mathematics in South African high schools?

## 1.5 Aim and objectives

The aim of the study is to explore how teachers integrate GeoGebra in the teaching of mathematics in South African high schools.

The objectives of this study are:

- to investigate how teachers perceive the integration of GeoGebra in teaching mathematics in South African high schools;
- to explore teachers' practices of integrating GeoGebra in the teaching of mathematics in South African high schools;
- to explore the PD support (if any) that is provided to teachers in teaching mathematics using GeoGebra in South African high schools; and
- to determine and account for teachers' understanding of and practices in the integration of GeoGebra to teach mathematics in South African high schools.

## 1.6 Significance of the study

The purpose of this study is to explore how teachers integrate GeoGebra software in the teaching of mathematics. It seeks to investigate and analyse perceived teachers' understanding of and practices in the integration of GeoGebra software and the PD support (if any) that is provided to teachers in teaching mathematics in South African mathematics classrooms using GeoGebra software.

The study aligns with the South African National Curriculum and Professional Development Framework for Digital Learning on the expectations of teachers on the integration of technology in teaching and learning. Specifically, I propose to explore the implementation of the e-learning policy in the teaching and learning of mathematics in high schools. According to Remillard and Bryans (2004:356), "[i]n order to teach differently, teachers need opportunities to learn mathematics in new ways and to consider new ideas about teaching and learning”.

This study seeks to specifically contribute in the body of knowledge by providing answers to the questions of whether the integration of technology in teaching mathematics in high school along with the expectation of the integration of technology, as according to the national curriculum, are effective and how teachers’ practices align with the policy on ICT Professional Development Framework for Digital Learning. Similarly, the study seeks to benefit teachers, learners and the Department of Education (DoE) and its stakeholders. Teachers may gain perspective and knowledge on how to integrate GeoGebra software in teaching mathematics and the extent to which GeoGebra enhances the learning of mathematics in a South African curriculum. Learners will gain a perspective of the mathematics topics from the visual aids provided for by the GeoGebra software. Furthermore, they will gain a deep understanding of mathematics and appreciation of mathematics as a school subject. The DoE and its stakeholders will be provided with information that will enhance their knowledge of how they might be able to better equip their training in order to improve the quality of teaching practices in high schools through the integration of GeoGebra in teaching mathematics.

The broad aim is to contribute to the body of literature relating to the increase in teachers’ skills in integrating ICT software such as GeoGebra in teaching high school mathematics and, consequently, the increase in mathematics performance of learners, as well as the resulting increase in the number of learners opting for mathematics-based subjects at tertiary level.

It is, therefore, imperative to ensure that teachers’ practices are understood in order to devise ways that can better support teachers through effective skills that embrace technology in teaching and learning. As general research indicates, a positive contribution is made by the integration of ICT into teaching and learning. This study also seeks to contribute to the increase in the number of resources that is geared towards improving the quality of resources for learners, curriculum developers and teachers and provide them with the views of teachers in the integration of GeoGebra in teaching mathematics in high schools.

## 1.7 Scope and delimitations of the study

The study is based on the views and experiences of only mathematics teachers who use GeoGebra in teaching mathematics in South African high schools. The study focused on how teachers integrate ICT, particularly the mathematics software GeoGebra, in teaching high school mathematics. Data were collected from four mathematics teachers at three different high schools in the Bojanala district, North-West Province. The study purposively sampled four teachers who had participated in training focused on the integration of GeoGebra. However, the study is not entirely representative of the stakeholders in the integration of GeoGebra in the teaching of mathematics in South African high schools due to the small sample used.

## 1.8 Operational terms

### 1.8.1 Information and communications technology

Information and communications technology is commonly termed "ICT". It is a combination of information technology (IT) and communication(s) technology (CT). According to the DoE (2004:15), IT is used to describe the parts of the equipment (hardware) and computer programs (software) that allow us to manipulate and present information by electronic means. CT describes telecommunications equipment through which information can be sought, sent and accessed, for example computers, phones and tablets. The whole term "ICT" represents the combination of information and communication technologies. It represents the combination of network, hardware and software as the means of communication and engagement that allows for the acquisition of information and knowledge.

### 1.8.2 ICT integration

ICT integration is defined as the use of ICT to introduce, reinforce, supplement and extend skills (Pisapi, 1994). Integration of ICT refers to the integration of relevant ICT software into the curriculum for a better understanding of the taught concept.

### 1.8.3 Teacher practice

The way teachers conduct their core business of lesson planning, lesson delivery and assessment is called a "teacher practice". When used in the context of classroom instruction where the integration of technology is acknowledged or important, it refers to the teacher's ability to demonstrate an understanding of the technology in its ability to enhance learning and create a positive learning experience for learners (Klieme & Vieluf, 2009).

### 1.8.4 GeoGebra software

GeoGebra is mathematics software generated to fill the important role of visualisation in mathematics. It is an application created to build geometric constructions and solve analytical and algebraic problems. It is available on “multiple platforms with desktop applications for Windows, Mac, OS and Linux, with its tablets apps for Android, Apple and Windows and its web application based on HTML5 technology” (Majerek, 2014:51). The GeoGebra software is equipped with features of geometry, trigonometry and algebra applications, such as Dynamic Geometry System and Computer Algebra System (CAS). This particular software has established its place as a popular tool that can be used at all levels from primary school to university. It can be used to enhance the learning of mathematics topics in algebra, geometry, trigonometry and calculus (Aktumen & Kabaca, 2012; Kagizmali et al., 2011; Kutluca & Zengin, 2011).

## 1.9 Thesis outline

This study is divided into five correlated chapters:

**Chapter 1: Introduction**

Chapter 1 provides the background context of the study and states the detailed problem and its justification, significance and the delimitations of the study.

**Chapter 2: Literature review**

This chapter focuses on an in-depth review of existing literature on the complexity of the integration of ICT and ICT software, with a focus on GeoGebra software in mathematics teaching. A detailed discussion of the conceptual framework underpinning the study is also provided.

**Chapter 3: Research design and methodology**

The discussion in Chapter 3 entails interpretivism as the research paradigm of the study and the appropriateness of this paradigm. The discussion also includes the research approach and design, data collection and analysis, credibility and trustworthiness of the study and ethical considerations.

**Chapter 4: Analysis and interpretation of data in the study**

The data collected will be analysed in the form of case studies that are interpreted and chronicled in the form of a narrative for each selected teacher.

**Chapter 5: Discussion of the findings and conclusions**

Chapter 5 presents a discussion of the findings, conclusions and the implications thereof for both policy and practice. In this chapter, I explore the relevance of the findings and conclusions of the study to the integration of GeoGebra and related mathematics software tools.

# CHAPTER 2: LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

## 2.1 Introduction

The study seeks to investigate how teachers integrate GeoGebra software into the teaching of mathematics in South African high schools. The first part of this chapter reviews literature on the integration of GeoGebra software in the teaching of mathematics in South African high schools, with the objective of providing a conceptual and contextual basis for the study. The study is focused on the teaching of mathematics in high school, specifically the FET band, which is from Grade 10 to Grade 12. The first part also discusses the PD of teachers in the integration of available mathematics software for teaching mathematics in South African high schools. The reviewed literature encapsulates the research, practices and experiences relating to the integration of ICT software in South Africa, Nigeria, Ghana and Zimbabwe. Literature from South Africa, Zimbabwe, Australia, Denmark, the United States of America, the United Kingdom, South Korea, Malaysia and other international communities is reviewed.

The second part of the review explores the conceptual framework used in this study. Technological pedagogical content knowledge (TPACK) is the conceptual framework used within this study to explore teachers' practices in the integration of ICT software in teaching high school mathematics. As part of the discussion, the six categories of knowledge that are defined within TPACK are thoroughly examined. This is followed by a discussion on the justification of choosing TPACK as the conceptual framework within this study.

## 2.2 Integration of ICT into mathematics teaching and learning

The use of ICT in a learning environment is traced back for a couple of decades in the history of educational technology. In the 1980s, when pencil and paper dominated the education system, Dr Seymour Papert projected the use of computers to dominate the learning environment. Dr Papert is a leading education theorist who envisaged that learners and teachers would use computers as instruments for learning and enhancing invention (Xu, 2017). The need for the integration of ICT in education has been fuelled by the widespread ownership of mobile computing devices such as iPad and cell phones (Tay et al., 2017).

Education in the 21st century has drastically changed with the widespread use of technology. ICT is profusely involved in our daily lives; every time a cashier scans a barcode in a supermarket, when someone uses an email for a bank transaction or when someone makes an inquiry about a loan, account or water bill, ICT is used. In order to establish the required skills to live in the 21st century, business, non-profit and education leaders were interviewed. It was found that learners need survival skills, including critical thinking and problem solving, collaboration and leadership, agility and adaptability, initiative and entrepreneurialism, effective oral and written communication, assessing and analysing information, curiosity and imagination (Saavedra & Opfer, 2012). To these, the use of technology as a tool for learning can be added (Tindowen et al., 2017).

The general integration of ICT in learning has allowed teachers to create learning materials that are innovative and promote an active learning environment that is learner-centred. This promotes learning that is relevant to the development of learners with 21st-century skills (Saavedra et al., 2012; Tindowen et al., 2017). The learner-centred teaching environment is the opposite of the traditional method and (teacher "talk-and-chalk") learning environment where the teacher and the textbook have been the central part of learning (Chimuka, 2017). In a traditional learning environment, the strategy allows learners to be passive, unlike the modern learner-centred learning environment, which encompasses an active learning strategy that is about the active engagement of learners. According to Armah and Osafo-Apeanti (2012), "traditional" pedagogical practices essentially promote instrumental understanding and diminish the conceptual understanding of concepts. A learning environment that relegates learners to be passive participants in their learning and lacks the connection of concepts with real-life situations leads to learners finding the subject (e.g. mathematics) boring. Conceptual understanding of the taught concepts is demonstrated in various ways, including ICT. Hence Bower et al. (2010) postulate that ICT promotes active engagement between learners and teachers, as well as among learners themselves. The integration of technology as a learning tool is thought of as the learners' ability to manage their learning and produce products using relevant ICT tools (Tindowen et al., 2017).

Studies have shown benefits of the integration of ICT, which confirm that overall learner performance in the teaching and learning process is enhanced when technology is integrated into learning (Agyei & Voogt, 2011; Al-Ammary, 2012; Witte & Rogge, 2012). The integration of ICT in mathematics teaching and learning not only enhances the learners' mathematical understanding but also develops their mathematics reasoning and problem-solving skills (Mendezabal & Tindowen, 2018). ICT is further known to increase learner engagement in classroom learning activities (Al-Absi & Abed, 2014; Al-Ammary, 2012).

However, there is an observed sluggish uptake of the integration of ICT in the field of mathematics, which calls for concern. With the current decline in mathematics and performance and learners' negative perception of mathematics, effective intervention strategies need to be evaluated and re-invented. The benefits of the integration of ICT in mathematics are perceived to be an antidote for the challenges experienced in the teaching and learning of mathematics.

It is for this reason that educational institutions around the world have taken the initiative to integrate ICT into teaching and learning with the hope that it will improve learners' understanding of the taught content (Tay et al., 2017). There is also a global realisation that the effects of ICT are important in the workplace, everyday life and modern educational systems. Furthermore, education institutes try to structure their curricula and classroom facilities around accommodating the integration of ICT in teaching and learning (Buabeng-Andoh, 2012).

Technology is perceived to be one of the means of making difficult aspects of mathematics easier and fun to learn (Tay et al., 2012). ICTs have also become important tools for business, entertainment and homes. It is, therefore, a general expectation of employers, policymakers and society in general that learners finishing school or tertiary education in this era ought to have some level of ICT competency (Ertmer & Ottenbreit-Leftwich, 2010). Throughout the history of education, mathematics is one of the school subjects that have been thought of as abstract and difficult to understand by students. On the other hand, it is regarded as an important subject with regard to various aspects of our society. Curri (2012) identifies ICT as an important tool and vital component available to support visualisation and interactive media that assist in the representation of abstract concepts, logical application and solving problems.

> *Technology is not a silver bullet and cannot – by itself – produce the benefits we seek in learning, but without technology, schools have little chance of rising to 21st century expectations. Synthesis of best available evidence consistently indicates the potential for positive effects when technology as a key ingredient in well-designed learning systems. (Culatta & Adams, 2014:15*

Al Achhab Sakina (2013:501) suggests, "The use of computers in mathematics education falls within the scope of practice innovation. It is an educational approach that gives the teacher the opportunity to invest in multidisciplinary teams, therefore a source of mutual enrichment." The use of technology is an innovation that has been accepted by society over time as an important model of change. It allows teachers opportunities to be innovative in their classrooms and, therefore, has gained the status of being a source of mutual enrichment. Different countries have various views on the integration of ICT in their teaching of mathematics. Tay et al. (2017:1) proclaim, "Information and communication technology (ICT) has permeated almost all aspects of our lives. Educational institutions around the world have embarked on a quest to integrate ICT teaching and learning in the hope that it will enhance students' learning."

### 2.2.1 Factors facilitating the integration of ICT

There is a consensus on the positive impact that the integration of ICT and ICT tools has in teaching and learning. However, some literature sources dispute the benefits of the integration of ICT in teaching and learning. A study by Skryabin et al. (2015), based on the TIMSS 2011 data and the Programme for International Student Assessment 2012 data, analysed the influence of the ICT development level and use on students' achievement in mathematics, among other subjects. It was found that using ICT at school had a negative impact on students' academic performance. According to Alazam et al. (2012:70), ICT can do wonders in teaching and learning if used wisely by well-trained teachers. ICT enhances the teaching and learning process by increasing learners' motivation. The use of ICT in the classroom helps in the explanation of difficult concepts so that learners are able to easily understand concepts.

ICT alone does not translate to success in taught subjects, but there are other important cofactors to consider. It is imperative to note these factors that facilitate the integration of ICT for learning. In a study by Tay et al. (2017), from the interview sessions with the teachers, four cofactors, which when incorporated into the integration of ICT in learning lead to improved outcomes, have been identified as follows: commitment of the school administration; technological infrastructure; school culture and PD efforts; and support from related external institutes.

Firstly, the commitment of the school administration is important to ensure support for teachers on how to use technology for teaching and learning. Well-resourced government schools have computer laboratories, but the majority of these are not utilised for the intended purpose (Ford & Botha, 2014). School leadership, especially school principals, should be able to use the technology themselves and offer support to teachers (Kannan et al., 2012).

Secondly, technological infrastructure is all about ensuring the relevant computing devices, and the installation of access to the Internet is imperative. There is also a need to ensure that the school has reserved the services of technicians in order to assist teachers and learners with their technical challenges.

Thirdly, the school culture and PD, which is focused on the training of teachers on how to integrate ICT during the teaching and learning of mathematics, are important (Hismanoglu, 2012). This could be done, for example, when a new teacher is recruited to the school after ICT integration has been launched; the new teacher will be inducted and offered the necessary professional training in technology-enhanced learning in the form of peer sharing and on-job training.

Lastly, support from related external institutes refers to the school's involvement with external institutes to provide ICT equipment such as laptops, desktops, tablets and Internet connections. Schools may work with local and international institutes of higher learning to acquire the latest developments in hardware and software technology. Aydin et al. (2016), Buabeng-Andoh (2012), Karaca et al. (2013) and Van Wyk (2014) all are of the view that the main factors that affect the integration of ICT into the curriculum relate to the teacher. Some researchers believe that teachers' attitudes have an impact on the integration of ICT (Cakiroglu, 2015; Pamuk et al., 2013; Sahin et al., 2013). Teachers' pedagogical beliefs are also deemed to have an influence on the integration of ICT in teaching and learning (Baser-Gulsoy, 2011; Mumtaz, 2000). Teachers' involvement is a crucial element in the integration – from planning the lesson, understanding how to use the ICT tools and software and having knowledge of the selected tool and software connected with the prepared lessons.

For this reason, this study seeks to explore how teachers integrate GeoGebra software in their teaching of mathematics in South African high schools. The section below discusses the integration of ICT in the teaching of mathematics in various countries and explores the integration of ICT in South African schools.

### 2.2.2 Integration of ICT in the teaching and learning of mathematics in international communities

The use of technology is widely supported and, as a result, the International Society for Technology in Education has formulated technology standards for teachers and students. This is to ensure that mathematics can be taught through the use of technology. The integration of technology standards for teachers, as set by the International Society for Technology in Education (2007), includes employing teaching practices that encourage learners to learn and be creative, design and develop a learning experience that includes some form of technology as part of learning and assessment. Furthermore, these practices should encourage and model digital citizenship and responsibility and engage in PD enrichment.

Various countries choose how they implement international guidelines. The United States of America have the Common Core State Standards Initiative (CCSSI, 2015). These standards include guidelines for mathematics practices that describe various skills and knowledge that learners need in order to succeed at tertiary level, in their careers and in life in general (CCSSI, 2015). That means teachers should seek to develop important skills in their learners and the said guidelines provide ways in which they could develop those skills. Guidelines also are another important way of ensuring support to teachers and ensuring that similar standards are enforced in all schools.

The CCSSI calls for greater focus on mathematics and demands three major shifts, namely greater focus on fewer topics, coherence and rigour. The "fewer topics" means only limited mathematics topics are covered per grade. For example, the American

Grade 8, which is equivalent to Grade 9 in South Africa, only covers linear algebra and linear functions as the major work content. Coherence refers to the linking of mathematics concepts and thinking across grades. Mathematics topics are connected and form a coherent body of knowledge forming interconnected concepts. The learning of mathematics concepts connects across grades so that students can build new understanding from the work covered from the previous grade. Finally, rigour is described as the deep, authentic command of mathematics concepts and avoids mathematics complication by introducing complicated concepts in the early grades (CCSSI, 2015).

The South African curriculum document emphasises coherence and rigour. There is a connection of mathematics topics from Grade 7 to 9 and from Grade 10 to 12. The connections in mathematical concepts build from easy concepts to difficult concepts. For example, in the Grade 8 algebra topic, learners are expected to find the product of two binomials. In Grade 9, learners are expected to find the product of trinomials, according to the mathematics FET CAPS policy (DBE, 2011). However, the South African curriculum lacks focus on fewer topics in the curriculum. For example, FET learners are expected to cover 10 mathematics topics, whereas similar grades in America cover three mathematics topics.

The above CCSSI for mathematics needs to be implemented in the classroom and the mathematics practice should guide teachers on how to teach each of these concepts. These practices are there to guide teachers in order to develop learners' mathematics skills. The CCSSI (2015:3-4) stipulates that one of the necessary mathematics practices is to "use appropriate tools strategically". In a mathematics learning environment, available tools need to be used when solving a mathematical problem or connecting mathematics to real-life situations. The tools referred to include pencil and paper, ruler, protector, calculator, a spreadsheet, CAS and statistical package or dynamic geometry software. Proficient students need to be familiar with these tools, make decisions about when it is appropriate to use which tool and have a logical explanation for the decision. These students know the digital contents of various websites and are able to use them to pose or solve problems.

Taiwanese government issued a mandate on the integration of technology in January 2007 under the *Technology Education White Book*. The book mandates teachers to use technology during teaching and set a goal that 90% of teachers should integrate technology by the year 2011 (Liu, 2011).

In Botswana, Nigeria and Korea, teachers find geometry concepts too abstract to comprehend and teach, which has an effect on their teaching of geometry and on learner performance (Nkhwalume & Liu, 2013). ICT has been introduced as part of the intervention strategy in dealing with the mathematics challenge in the 21$^{st}$ century. Baya'a and Daher (2013:46) affirm, "The integration of ICT in the teaching and learning of mathematics, as a result of ICT educational affordances, helps students to have a better achievement in mathematics." Kafyulilo and Kisalama (2012) and Van Rooy (2012) concur that the integration of ICT in teaching has the potential to improve the quality of education.

Curri (2011) conducted a study in Albania on the integration of ICT in mathematics teaching and learning with a focus on the learners' understanding of mathematics and their attitudes and opinions in relation to the trigonometry aspect of mathematics. It was found that the use of technology supported the learning aspect of trigonometry and resulted in improvement in learner performance. In Malaysia, the Ministry of Education regards the integration of ICT into teaching and learning as a high priority. Hence the Malaysian Ministry of Education has made continuous efforts to enhance teachers' ICT skills in all schools in Malaysia (Kannan et al., 2012).

Various studies have been conducted to measure the impact of the integration of ICT in various countries. A study was conducted in South Korea by Song and Kang (2012) to analyse the impact of ICT on the achievement of students from different grades in primary and secondary schools. The national assessment results used to measure the impact of the use of ICT found that there was a positive correlation between achievement and the use of ICT in the teaching of mathematics. Countries that perform better in mathematics have incorporated ICT in their teaching and learning of mathematics. These countries have introduced ICT in their education system as a way of transforming the learning environment and improving mathematics performance. Over time, the positive correlation has shown.

### 2.2.3 ICT integration in teaching and learning of mathematics in South Africa

In South Africa, the integration of ICT has been in process since 1980 (Mdlongwa, 2012). The initial integration was focused more on computers as the ICT device, and this later grew into the integration of tablets. The DoE (2004) further introduced the e-Education policy, which suggested the inclusion of ICT into the curriculum by 2013. However, the Ministry acknowledged that it could not take responsibility alone for the integration of ICT in schools. Expert guidance was sought from universities, the private sector and human resources within non-governmental organisations.

The integration of ICT tools has been supported by sponsors focusing on various aspects of integrating ICT in teaching and learning. A few initiatives are briefly mentioned below.

The Mustek e-Learning initiative focuses on how technology can be made relevant to the society and responds to the challenges that result in technology not being used in some schools (Van Wyk, 2014). The Khanya project also focuses on ensuring that technology is implemented in schoolwork. Further projects in the integration of ICT in teaching and learning in South African schools are SchoolNet, Gauteng on-line, the Connectivity Project in the Northern Cape and ICT for Rural Education Development (ICT4RED) in the Eastern Cape (Assan & Thomas, 2012; Dzansi & Kofi, 2014). SchoolNet also supports teachers from the North-West Province, offering courses that guide teachers in the integration of ICT software into the teaching and learning of various subjects, including mathematics.

The DBE has introduced the *Guidelines for Teacher Training and Professional Development in ICT* (2007) for teachers on how ICT may be integrated in the teaching and learning environment (Hindle, 2007). Some provinces, for example North-West, on which this study is centred, employ these guidelines to select the mathematics software to use as part of the integration of ICT in the teaching of mathematics. Notwithstanding that, in South Africa, there is more emphasis on the integration of technology in general and little emphasis on the integration of mathematics software in particular. There is also limited information on the inclusion of the integration of ICT or ICT software in the curriculum. This idea will ensure standard guidance and inclusion in the teaching and learning of mathematics with the assistance of various technological tools, if properly executed.

### 2.2.4 Strategies of teaching mathematics using ICT

According to Salomon (2016), computing devices are a critical element of teaching and learning; however, using these is futile without supporting pedagogical strategies. There is a move to integrate ICT in the teaching of different subjects, but due to the uniqueness of each subject, it is necessary to develop different sets of instructional strategies. In mathematics, for example, the Mathematics FET CAPS policy (DBE, 2011:53) states that the mathematics curriculum consists of 45% complex higher-order and problem-solving procedures. Another assertion is that learners have prior knowledge; so, they come to the learning situation with ideas about the introduced concepts.

Teachers need to consider these ideas and make them relevant within the conceptual structures. It is, therefore, intriguing what strategies may be deemed necessary when ICT is an integral part of learning. Learners are perceived to have their own distinctive ideas about reality and generate their own meaning structures to cope with everyday living. These ideas need to be channelled correctly to ensure that effective learning takes place. Different researchers share different strategies in teaching mathematics with technology, but the emphasis that learning has to happen with and from ICT is the same (Tay et al., 2017). According to Drier et al. (2000:67), the following are guidelines for the appropriate integration of technology in a mathematics classroom: "Introduce technology in context; Address worthwhile mathematics with appropriate pedagogy, take advantage of technology, connect mathematics concepts and incorporate multiple representations."

However, it is important to consider teaching strategies that will inculcate the suggested guidelines. Teaching strategies in mathematics include problem-based learning, collaborative learning, the social constructivist approach and blended instruction.

In a study by Karami et al. (2013) that investigated problem-based learning and ICT integration in a quest to improve learner performance in mathematics, it was found that the integration of ICT applications improves learner performance and enhances learner-centredness in problem-based learning. It was also found that not only does ICT integration promote learner engagement but it also enriches teachers' content knowledge (CK) while achieving the set objectives of the lesson.

Fu (2013) advocates for collaborative learning when ICT is used as part of learning. He postulates that the integration of ICT software not only facilitates learners to acquire knowledge but also creates a learning environment where learners have the opportunity to share their varied learning experiences. There is a growing assertion from the literature that confirms that the integration of ICT enhances the teaching of mathematics by linking learners' existing knowledge with the new information. Pinheiro and Simõe's (2012) study sought to understand how the integration of ICT enhances the active and collaborative learning environment. The study found that ICT encourages change from traditional teaching and promotes active and collaborative teaching and learning that build on learners' prior knowledge.

Mbati and Minnaar (2015) support this view in their finding that the use of ICT fosters the social constructivism approach to teaching that considers learners' prior knowledge when developing a new concept. ICT is further known to enhance the interaction between teachers and learners, thereby creating an active learning atmosphere (Tay et al., 2012:743). According to Mokhtar et al. (2010), the use of a student-centred learning approach develops the potential of learners to be both creative and critical in their thinking.

According to Lloyd-Smith (2010), blended learning instruction is suitable for learning that includes technology because it offers a variety of choices for content delivery. Blended learning can also be used when teaching online or in a classroom environment. Garnham and Kaleta (2002) share this view in their study that found that learners acquire more knowledge when taught in a blended learning environment as opposed to traditional classes.

Lloyd-Smith (2010) argues that blended instruction offers more choices for content delivery and is more effective than teaching, either fully online or fully classroom-based. In their studies, Garnham and Kaleta (2002) and Lloyd-Smith (2010) reported that learners learn more in blended learning environments than they do in comparable traditional classes. Blended learning offers learners an opportunity to work independently. Learners are more creative and excited about learning when they work independently especially in a subject such as mathematics that is about reasoning and solving problems. When learners take ownership of their learning and are independent in their learning, it is referred to as "autonomous learning". Lan (2018:856) holds the following view:

> *Autonomous learners learn more efficiently and effectively because they tend to regularly reflect on their own learning process and therefore they take control of their own learning. With the perception of learner ownership, autonomous learners are more independent and responsible. Thus, while managing their own learning, they do not suffer from the lack of learning motivation. They are usually proactive and are willing to take risks during the learning process.*

Khouyibaba (2010:638) postulates that technology offers an allowance "to better capture the attention of the students and enables them to better understand and master mathematics concepts". Other studies also confirm that the integration of technology helps students to be knowledgeable and reduces teacher-centred learning. Moreover, it allows teachers an opportunity to assist other learners who may be struggling with specific concepts (Chigona et al., 2014; Zindi & Ruparanganda, 2011).

## 2.3 Integration of ICT software in mathematics teaching and learning

The literature review in this section is focused on the role and impact of ICT software that is available in the teaching of mathematics. However, my study focuses on the integration of GeoGebra software in the teaching of mathematics in South African schools. This section encapsulates the integration of various types of mathematics software, including GeoGebra software, in various countries. Literature is reviewed on mathematics software and GeoGebra in particular that has been integrated into teaching mathematics at various levels in high schools in several countries. Most literature reveals the positive impact of using GeoGebra software in teaching mathematics. Hence, this study seeks to explore how teachers integrate GeoGebra software in teaching mathematics in high school.

Mathematics covers complex topics and therefore it is important that teachers integrate technology in their teaching. The integration of technology will allow a diverse teaching approach and an interactive mathematics lesson. However, this will be made possible if teachers evaluate "technology-driven instruction strategies and activities such as mathematics software that will enhance students' attitude, conceptual skills, and procedural skills" (Mendezabal & Tindowen, 2018:393) in mathematics courses. Learners have negative views about mathematics as a school subject, and these views are compounded by instructional strategies that do not conceptualise mathematics ideas (Iji et al., 2017). The integration of ICT with specific mathematics software seeks to address these negative views. Mathematics software tools are regarded as ritualistic and engaging to learners. Hence, the teaching strategies that are in accord with the integration of any technology is an active learning strategy, which is learner-centred.

The Malaysian government has taken the initiative to provide access to the Internet and a virtual learning environment via IBestari Net to schools. This was meant to enhance the integration of ICT with specifically loaded software for quality teaching (Malaysian Ministry of Education, 2012).

Various technologies have come to be used in teaching and learning in recent years. Technologies commonly used in the teaching and learning environment are tablets, smartboards, cellular phones (Watson, 2015) and calculators (Sivakova et al., 2017:470). This study is more focused on the actual software or programming language that is instilled in these ICT tools to enhance teaching and learning mathematics. Berežný (2015) is of the view that for effective integration of technology in mathematics, the teacher has to use various ICT software in his or her teaching. He acknowledges that it is difficult to choose the right software to use for teaching mathematics. However, the right software should be applicable to the task and easily accessible and learners should be able to use it. Recommended ICT software tools are MS Office, Libre Office, Matlab and Octave. Mathematics requires the development and mastery of problem-solving procedures. These procedures include the manipulation of equations, logical application and an attentive approach to ensure the accuracy of solutions. The use of mathematics software has the ability to enforce such procedures (Iji et al., 2013).

Kumar and Kumaresan (2008) state that mathematics concepts involve difficult and abstract ideas that make it difficult for most students to understand. A mathematics software program called "Computer Algebra System" (CAS) is known to offer both an opportunity and a challenge to present mathematics concepts in a manner that is understandable to most teachers and learners.

According to Zilinskiene (2014), there are four aspects of any mathematical software, including GeoGebra, that can be used as an effective part of mathematics teaching and learning. The first is a multiple display option, which is the availability of various ways of displaying mathematics content, for example displaying a quadratic expression, $x^2 - 1$ into graph form. A teacher may further display what happens when the equation changes to $x^2 + 1$. Demonstration and visualisation are important in understanding mathematics concepts during the process of problem solving and learning. The second is experimental work, which describes the possibility of learners using experimentation in order to gain an understanding of the taught mathematics concepts. Thirdly, the elementarisation of mathematics methods, for example mathematics software, will have tools that learners can use to draw or design mathematics concepts such as different types of triangles with their properties. The last aspect is connectivity, which is described as opening up new opportunities for shared knowledge construction and learner autonomy over their mathematics work.

All these aspects of mathematics software are important in guiding teachers in their lesson planning. As Almadhour (2012) pointed out, teachers are important in the effective integration of ICT tools in teaching and learning. This view is supported by Hismanoglu (2012:183), saying that "the prospective teachers having five ICT-related courses displayed better attitudes in comparison to those not completing this training period". A well-executed lesson needs proper planning by a teacher who has an understanding of various aspects of technology, which make learning mathematics understandable and interesting. Various countries advocate for the integration of specific mathematics software in their teaching, and some endorse mathematics software in their policy.

Denmark and Australia advocate for CAS to be made part of their curriculum reform. In Australia, Asp, Ball, Flynn and Stacey (2002) introduced CAS software into the mathematics curriculum in the project called "CAS in Schools: Curriculum and Assessment Teaching Project (CAS-CAT Project)". CAS software is encouraged in the teaching and assessment of mathematics content (Garner & Pierce, 2016). CAS has also been introduced to Danish upper secondary schools under the school programme reform of 2005. Since then, some of the mathematics examinations have been constructed in such a way that the learners need to have knowledge of CAS (Jankvist & Misfeldt, 2015).

In Botswana, most teachers use Scratch, Inkscape, SketchUp and Mathematica as the mathematics software packages of choice in their teaching. They believe the integration of mathematics software in their teaching promotes creative teaching methods that enhance the learners' ability to recognise and visualise different geometric figures (Kaino, 2008:1844; Nkhwalume & Liu, 2013:26-34).

Studies in Korea found that learners' creativity and innovation in mathematics lessons may be enhanced through the integration of graphic calculators and Geometer's Sketchpad in the teaching of geometry. These mathematics tools give learners an opportunity to investigate and experiment with angle measurements and the visualisation of various angles and geometry figures (Choi & Park, 2013:274; Meng, 2013:62).

In Zilinskiene's (2014) study of the integration of GeoGebra in mathematics education, suggestions were made on integrating GeoGebra software into specific mathematics topics covered in the Lithuanian curriculum. ***Table 2.1*** below illustrates the GeoGebra perspective in the Lithuanian curriculum and how GeoGebra software has been integrated in the mathematics topics (Zilinskiene, 2014). The Lithuanian curriculum includes mostly algebra and geometry, which makes it easier for teachers to follow in the curriculum implementation.

**Table 2.1: Application of GeoGebra software in Lithuanian education**

| **Mathematics content** | **GeoGebra perspective** | **GeoGebra application example** |
|---|---|---|
| Numbers and calculations<br>Algebraic measurements | Algebra and graphics | To explore how to increase or decrease numbers by units. To solve simple equations, inequalities, etc. |

| Mathematics content | GeoGebra perspective | GeoGebra application example |
|---|---|---|
| Geometry, numbers and calculations<br>Measurements | Geometry, numbers and calculations<br>Measurements | To plan and understand orientation in a plane by analysing main concepts to the right, to the left, above, etc. To focus on the appropriate concept (triangle, rectangle, square, etc.) |
| Tables and graphics | Numbers and calculations<br><br>Algebra<br>measurements<br>Statistics | To explore data, to influence data by changing them and to represent data by diagrams. |

Furthermore, South African, Korean and Nigerian teachers promote the integration of GeoGebra software to enhance the teaching of geometry and algebra in their mathematics lessons and enhance their visualisation skills (Meng, 2013:62; Mosia, 2016; Mukhari, 2016).

### 2.3.1 Integration of GeoGebra software in teaching mathematics in high school

GeoGebra was designed by Markus Hohenwarter as open-source dynamic mathematics software that incorporates geometry, algebra and calculus into a single, open-source, user-friendly package. GeoGebra originated in the master's thesis project of Markus Hohenwarter at the University of Salzburg in 2002 (Hohenwarter et al., 2008; Hohenwarter & Preiner, 2007). This software combined features of older software programs, such as Maple, Derive, Cabri and Geometer's Sketchpad (Saha et al., 2010). GeoGebra is a free and user-friendly program that connects geometry and algebra (White, 2012). Majerek (2014) refers to GeoGebra as an interactive geometry, algebra, statistics and calculus application that is intended for learning and teaching mathematics from the primary level of education to university level. GeoGebra allows for the creation of interactive web pages that are used for the demonstration and experimentation of various mathematics concepts (Hohenwarter & Lavicza, 2011). GeoGebra is available on multiple platforms, with desktop applications for Windows, OS, Linux and Mac. It also has tablet applications for Android, Apple and Windows (Majerek, 2014). The Ministry of Education in Australia has made GeoGebra software freely available at schools and university since 2006. It has also been adopted by Florida Atlantic University in America for their mathematics project to enhance the teaching and learning of mathematics (Hohenwarter & Preiner, 2007).

According to Preiner (2008), the integration of technology into teaching and learning in mathematics may be classified into two forms, namely virtual manipulatives and mathematics software tools. Virtual manipulatives comprise a specific learning environment, which requires minimal computer knowledge. In teaching mathematics through virtual manipulatives, learners explore mathematics ideas with limited computer skills or knowledge of mathematics software.

The mathematics software tools are selected for educational purposes and can be used in different mathematics topics such as algebra, geometry, statistics and trigonometry. Mathematics software tools allow flexibility and permit both teachers and learners to explore mathematics topics and gain conceptual understanding. Hohenwarter et al. (2008) define GeoGebra as a dynamic mathematics software tool for schools that can be used to learn algebra, geometry, statistics and calculus from primary school to university level. GeoGebra uses various mathematical built-in systems, namely GeoGebra CAS, GeoGebra Spreadsheet, GeoGebra Mobile and GeoGebra 3D (Kovacs, 2014).

- **GeoGebra CAS**

  GeoGebra CAS is a CAS that is important for symbolic computation of algebraic functions. It also allows learners to work with fractions, equations and formulas. ***Figure 2.1*** below represents the GeoGebra CAS view.

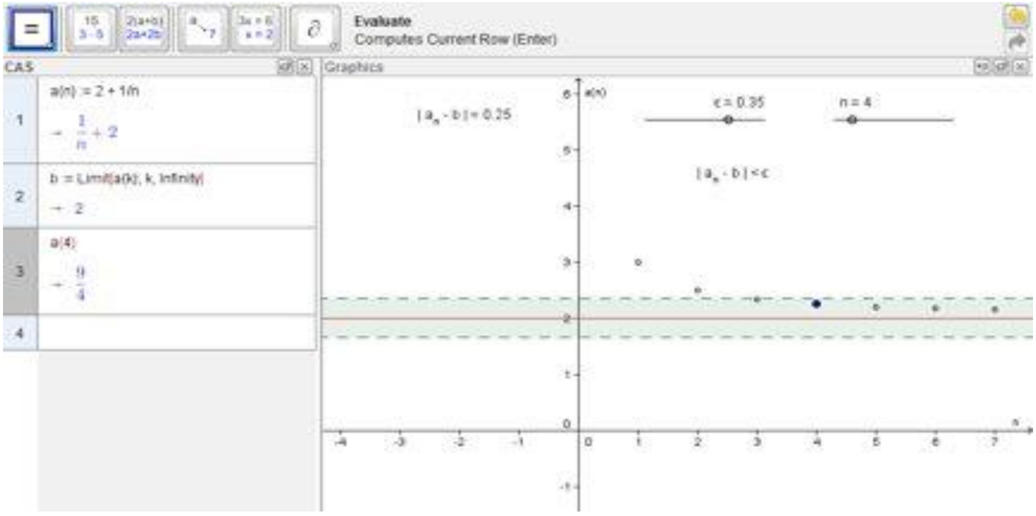

**Figure 2.1: Algebraic functions through GeoGebra CAS (Hohenwarter et al., 2008)**

- **GeoGebra Spreadsheet**

  GeoGebra Spreadsheet includes images and buttons to create diagrams representing line graphs or bar chars by choosing various available options. The user may import files from external sources or local files. ***Figure 2.2*** is an illustration of the spreadsheet view on GeoGebra.

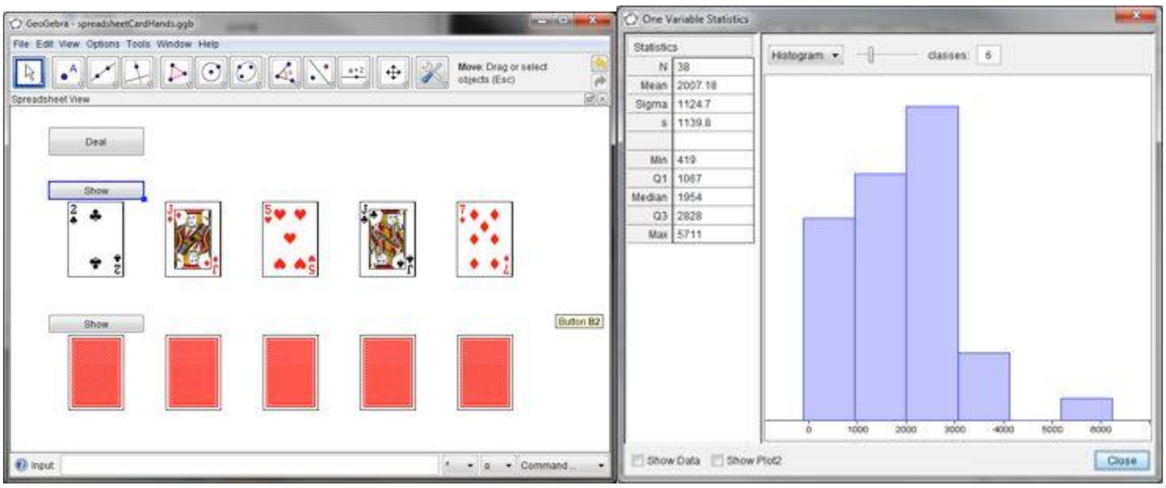

**Figure 2.2: Spreadsheet view on GeoGebra (Hohenwarter et al., 2008)**

- **GeoGebra Mobile**

  GeoGebra Mobile allows the user to use GeoGebra web applets referred to as "dynamic worksheets" on a wide range of devices, including various smartphones, such as iPhone on Apple, or other devices on Android platform (***Figure 2.3***). Figure 2.3 shows how GeoGebra may be used on cellular phones to explore various algebraic functions at the palm of one's hands. One may input various equations and explore the effects when variables change.

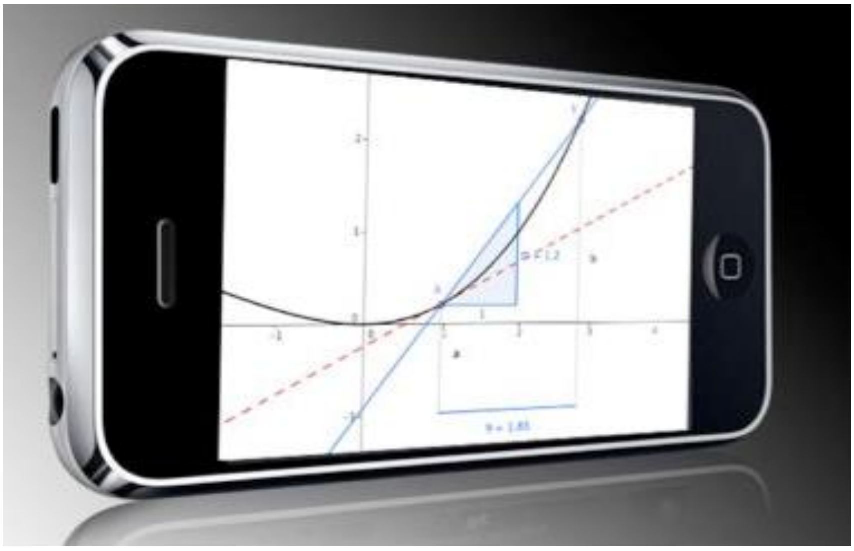

**Figure 2.3: GeoGebra mobile applet on a smartphone (Hohenwarter et al., 2008)**

In a study conducted by Chimuka (2017:3) on the integration of GeoGebra software in teaching mathematics in high school, it was found that "the integration of information technology (IT), GeoGebra in particular, into teaching and learning of secondary school mathematics can serve as a scaffold on which changes and developments in curriculum can be better managed".

Various countries have endorsed the integration of GeoGebra in the teaching of mathematics. In Slovakia, a study presented several possibilities of how GeoGebra might be integrated into education. GeoGebra is recommended for solving geometry tasks in the new Slovak curriculum for secondary schools (Gunčaga et al., 2012).

In Malaysia, Noorbaizura and Leong (2013) studied the effect of using GeoGebra to teach students' learning of fractions. The study showed that the use of GeoGebra to teach fractions is very effective. This was shown through the improved scores of the students in the experimental group. The findings highlighted that the students in the experimental group performed better than those in the control group who were taught using the traditional learning method. The software also enhanced visualisation and understanding of the concept of fractions for both the teacher and the students. GeoGebra is also endorsed in teaching geometry content in Malaysia (Azizul & Din, 2018).

A study was conducted in Singapore on the innovative activities that could develop geometric reasoning skills in secondary school mathematics with the help of the open-source software GeoGebra. The study found that students who were taught by using GeoGebra made good progress towards mathematical explanations, which provided a foundation for further deductive reasoning in mathematics. The conclusion was that the dynamic nature (drag feature) of the software influenced the form of explanation and that the students were able to generate the solution and respond with a proper statement. Consequently, it was found that GeoGebra made learning abstract concepts far more meaningful and helped students to visualise related concepts (Venkataraman, 2012).

In Indonesia, GeoGebra is also a mathematics tool of choice. Sudihartinih and Purniati (2019) present an argument that GeoGebra is free software that joins algebra, geometry and calculus in one package, where other packages treat them separately. For example, analytical geometry is viewed as difficult by most students because it is abstract and needs to be solved using algebraic principles.

A study was conducted in Nigeria to examine the effect of GeoGebra software on the performance of high school learners in mathematics. Two classes were divided into two groups – an experimental group and a control group – using random sampling. The experimental group was taught using GeoGebra and the control group was taught using the conventional method. The findings showed that the learners who were taught using GeoGebra performed better than the control group (Akanmu, 2015).

A study was also conducted in South Africa, in the Limpopo Province, about the effect of the integration of GeoGebra to teach linear functions in Grade 9. The study found that the learners who were taught using GeoGebra outperformed the learners who were taught without GeoGebra. It was, therefore, recommended that teachers should use GeoGebra as a tool as it is user-friendly and effective for planning lessons.

Similar studies were conducted in KwaZulu-Natal to establish the impact of the integration of GeoGebra in the teaching of Euclidean geometry. The study established that learners who had been taught through the integration of GeoGebra performed better than those who had not been exposed to GeoGebra (Bayaga et al., 2019; Mthethwa, 2015), thereby giving an indication that GeoGebra adds value and understanding of abstract concepts such as geometry.

### 2.3.2 Strategies of integration of ICT software in mathematics teaching

Various studies support the integration of GeoGebra in the teaching of mathematics. Zilinskiene (2014:74) is of the opinion that, looking from a perspective of the use of GeoGebra in mathematics classroom learning activities, there are three main activities to consider, namely "demonstration; exploration and modelling; and creation and experimental work".

With demonstration activities, the teacher presents learning activities created with GeoGebra. For example, a teacher can organise a slide presentation demonstrating various patterns of a parallelogram. A discussion can then follow where learners revise the material about the features of the parallelogram or any activities relating to the patterns of the parallelogram.

In exploration and modelling activities, a teacher may prepare learning objects and allow learners to examine, to find relationships and to discover some theory or constant patterns of the mathematics object under study. GeoGebra has such activities built into the software, for example where learners can explore the differences between a cube, a parallelogram, a rectangle and a square.

Creation and experimental work refer to activities where learners work with GeoGebra with the purpose of creating meaningful learning experiences or produce something new with their acquired knowledge. For example, for practical work, learners may be asked to draw symmetric and asymmetric pictures consisting of different pictures. Following that, learners may then experiment with their drawn pictures, analysing them in terms of objects that exist in nature, for example analysing the axis of symmetry of a flower.

Teaching mathematics in high school is an important step in preparing learners for their tertiary studies where mathematics is the theoretical background of their career aspirations.

ICT software tools are grouped into various categories that are used at various levels of education and for specific mathematics content (Novák, 2012:15-16):

- *Stand-alone products:* General software assigned to a single user or designated at a particular computer. It is used most often in high school because it is affordable and often meets the required standard of high school mathematics.
- *Various types of network licenses*: Licensed software used only at designated communal computers.
- *Technologies for web access*: Available from the Internet, for example Maple Net and web Mathematica.
- *Teacher-orientated tools*: Normally used by teachers for assessing learners in small and large scales, for example Maple.
- *Advanced professional modelling tools:* These are used outside the scope of high school mathematics content, for example Maple Slim, Simulink.
- *Unsorted tools:* For example, Wolfram Alpha.
- *Third-part open-source alternative:* For example, Octave as an alternative to Matlab because it is available free of charge.

In Serbia, there is a strong link between homework and the integration of ICT software in the learning of mathematics. According to Radović et al. (2018), a feature of software in the learning environment is to support the integration of ICT into mathematics teaching and learning practices. The integration of software allows for a space to shift away from an ineffective learning process, to offer new ways of thinking about mathematics learning and to strengthen the integration of ICT software in teaching mathematics. The Serbian Institute for the Advancement of Education mandates that teachers should give learners homework on a regular basis in order to establish the knowledge acquired at school.

It is, therefore, important that the strategies in the integration of ICT software encapsulate the presence of homework as part of teaching and learning. Homework gives learners an opportunity to acquire knowledge through practice and rehearsal of the work they did in class.

In a study by Radović et al. (2018), it was found that a positive attitude and willingness existed among learners to engage in e-learning homework activities. Consequently, when ICT software is integrated into teaching and learning, the teaching practice should include feedback on the e-learning homework activities as a way of encouraging learners to continue using the software at home.

Goos (2010) is of the view that teaching practices need to include classroom interaction with ICT software and specify the role of the teachers and learners in interaction. For example, in a situation where GeoGebra is used for teaching functions in Grade 10, teachers might need to consider in advance when they are going to introduce the features of GeoGebra in learning about functions. Then they should consider what the first function is they would draw using GeoGebra and what aspect of the function they want to illustrate using GeoGebra.

## 2.4 High school mathematics curriculum in South Africa

The administrative structure of South African schools is divided into primary school (Grade 1-7) and high school or secondary school (Grade 8-12). The high school band is divided into the Senior Phase (Grade 8-9) and FET (Grade 10-12). Mathematics is compulsory from primary school level until the last phase of GET, which is Grade 9. Mutodi and Ngirande (2014) state that mathematics performance in South Africa is one of the worst globally. For this reason, it is necessary to draw analyses of the status of education and what other researchers have observed to be a challenge.

According to Spaull (2013), mathematics challenges experienced in high school are a symptom of existing challenges in South African primary school mathematics classrooms. All teachers in primary schools are expected to teach mathematics, regardless of whether they have qualifications in mathematics or not.

Prew (2013) mentions that in the year 2012, 84 secondary schools did not offer mathematics at matric level. Less than 50% of matric learners from the two best performing provinces in South Africa – Western Cape and Gauteng – sat for mathematics in their final examination. This a reflection of the poor mathematics education in South Africa. My study focuses on how teachers integrate GeoGebra in teaching mathematics in South African high schools. It is, therefore, important to consider the content of mathematics that is covered in the South African curriculum and how that content relates to the mathematical knowledge and skills that GeoGebra has to offer.

Most researches point out that part of the challenge in understanding mathematics is its abstract nature and that it is difficult to conceptualise mathematical ideas. GeoGebra is regarded as one of the best mathematics software packages that illustrate mathematics ideas with its visualisation technique (Majerek, 2014) and thus helps to conceptualise difficult abstract mathematics concepts.

### 2.4.1 High school mathematics curriculum and GeoGebra integration

The National Curriculum Statement aims to produce learners who have the ability to "identify and solve problems and make decisions using critical and creative thinking". Learners also need to be able to use technology effectively, with the understanding that problem solving does not happen in isolation (DoE, 2012:5).

Teaching and learning of mathematics aim to develop critical awareness skills and the aptitude to handle mathematics problems in all learning environments and even in real-life situations. Therefore, when the curriculum is set up, it is supposed to fulfil this aim. On the other hand, integrating technology in teaching and learning is known to enhance and develop learners' problem-solving and critical thinking skills. This study will explore teacher practices in the integration of ICT software when teaching mathematics in the high school curriculum, focusing on the FET Phase. The mathematics curriculum in the FET Phase under the *Curriculum Assessment Policy Statements* (CAPS) is divided into ten main topics (DBE, 2011): Functions; Number Patterns, Sequence Series; Finance, Growth and Decay; Algebra; Differential Calculus; Probability; Euclidean Geometry and Measurement; Analytical Geometry; Trigonometry; and Statistics.

The section below covers the mathematics content in the South African high school curriculum and the GeoGebra tools that are available for integrating the taught content. GeoGebra offers geometry, algebra, statistics and calculus in a connected, user-friendly software environment. GeoGebra has a wide variety of features that make mathematics relatable (Dikovic, 2009; Kovacs, 2014; Majerek, 2014). Marejek (2014:52) described the main features of GeoGebra software as follows:

> *… free for non-commercial use, multi-platform; clear and easy understanding graphical user interface; rich database of ready-made examples; technical documentation in many languages; marking objects follow the mathematical syntax; ability to save a project in multiple formats; works with LaTeX; all objects in GeoGebra are dynamic; possibility to publish the work on the website through JavaScript.*

#### 2.4.1.1 Functions and GeoGebra integration

Functions refer to mathematics work that relates to the relationship between variables in terms of numerical, graphical, verbal and symbolic representations of functions. The functions may be represented in terms of tables, graphs, words and formulas. GeoGebra has tools that represent various functions in graphical forms. For example, the traditional pedagogy practises strategic teaching of quadratic functions. Quadratic equations are generally introduced in a standard form, such as $y = ax^2 + bx + c$. Learners are given various quadratic equations to factorise by finding factors, completing a square or a quadratic formula substitution method. Through this approach, learners are not engaged in any activities that require them to investigate the properties of the quadratic equation and observe the application of the equation in real-life situations (Armah et al., 2012).

In investigating a quadratic equation using GeoGebra software, firstly, graphs may be drawn using the graphing software. Secondly, learners may work on a task where they explore the effect of altering the coefficient of a quadratic equation (e.g. in the function $y = 4x^2$, 4 is a coefficient of $x^2$). The figure below indicates the change in the shape and location of the graph when the coefficient changes.

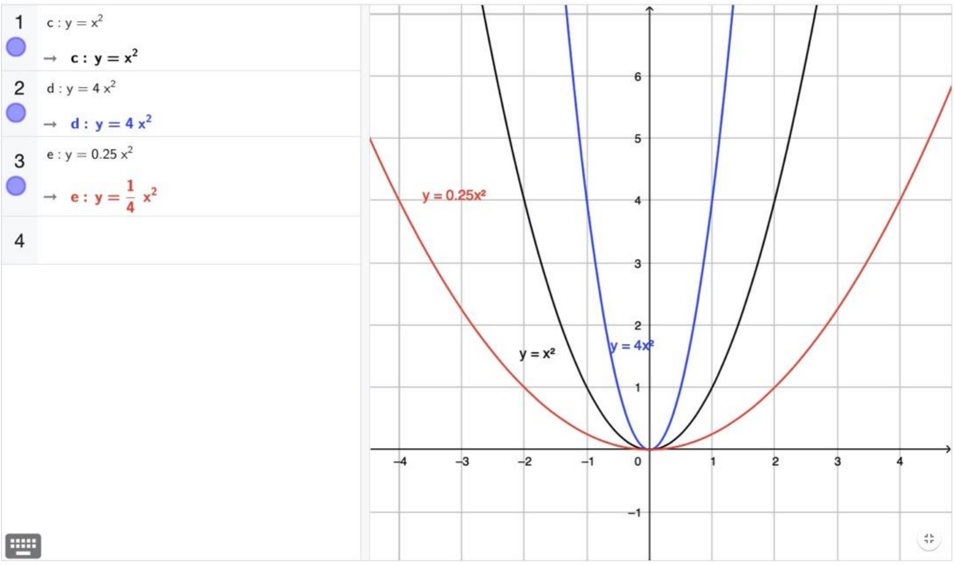


**Figure 2.4: An illustration of the implementation of GeoGebra in teaching quadratic functions (Armah et al., 2012)**

### 2.4.1.2 Algebra and GeoGebra

This section of the content area gives learners an opportunity to understand the meaning of different kinds of numbers (Campbell et al., 2013:5), namely (1) natural numbers ($\mathbb{N}$), for example $\{1;2;3;\ldots\ldots\ldots..\}$; (2) whole numbers ($\mathbb{N}o$), for example $\{0;1;2;3;\ldots\ldots\ldots..\}$); (3) integers ($\mathbb{Z}$), for example {……; -3;-2;-1;0;1;3;……}; (4) rational numbers ($\mathbb{Q}$), for example $\{-8.25;\ -\frac{11}{2};\ -4;\ -2;-1;0;1,1.809,2;\ldots\ldots\}$; and (5) irrational numbers, which are real numbers that are not rational, for example $\pi = 3.141592653589793\ldots\ldots\ldots$.

The exercise below (***Figure 2.5***) is an activity from GeoGebra illustrating the application of number concepts, specifically the integers. In this exercise, learners are required to observe a situation of change in temperatures (Stuckey, 2017). The scenario is as follows: At midday, the temperature was five degrees Celsius. By late afternoon, the temperature had risen by six degrees Celsius. What was the temperature in the late afternoon?

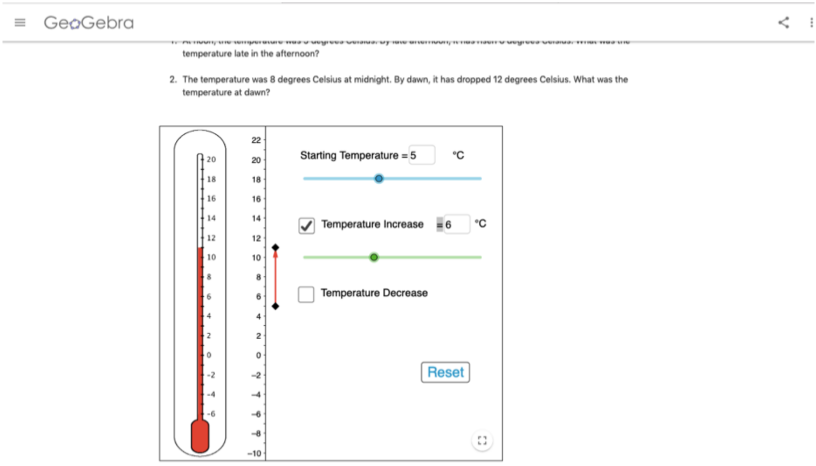


**Figure 2.5: GeoGebra illustration of number concept on integers**

The algebra section of the curriculum also encapsulates the investigation of algebraic expressions and the simplification of exponents. Learners have to understand the mathematical rules and language that are necessary for effective learning (DBE, 2011). For example, when dealing with algebraic concepts, when one needs to multiply the binomials, binomial refers to a term that has two terms, $2x - 2$. See the example below in ***Figure 2.6***.

First, it will be important for learners to understand that they have to apply the distributive law in order to expand the given function. They also need to understand that in order to get the correct answer, they need to apply the exponent rule that $a^m + a^n = a^{m+n}$, for example $2x \times 8x = 16x^2$ $2x * 8x = 18x^2$ in the figure below.

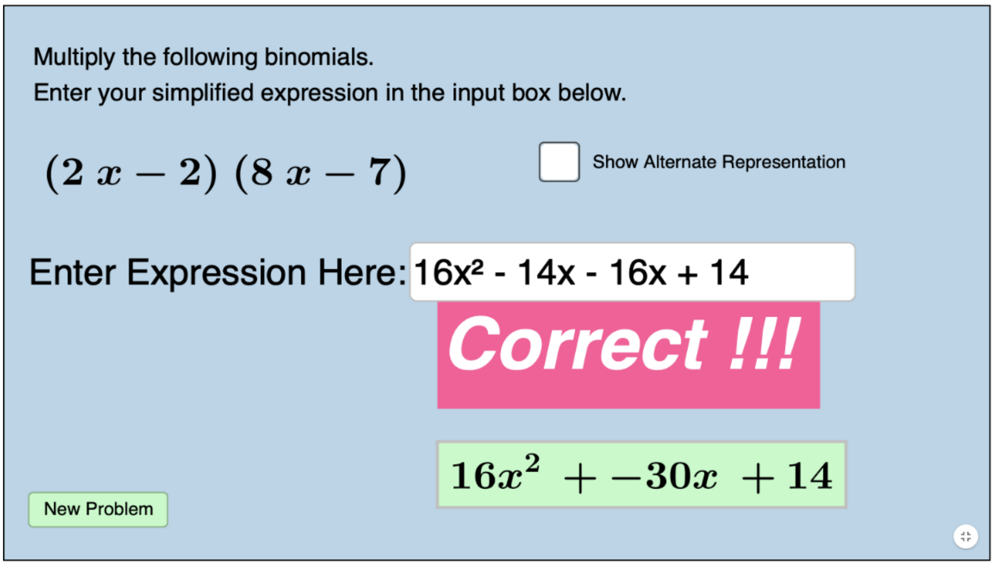


**Figure 2.6: GeoGebra illustration for solving quadratic equations using GeoGebra (Brzezinski, 2017)**

#### 2.4.1.3 Euclidean geometry and measurement and GeoGebra

The Euclidean geometry and measurement section in the FET South African curriculum encapsulates the investigation of and form conjectures about the properties of special triangles, quadrilaterals and polygons (isosceles, equilateral and right-angled triangle, e.g. the kite). Measurement focuses on the selection and use of appropriate units, instruments and formulas to quantify the characteristics of events, shapes, objects and the environment. It relates directly to the learner's scientific, technological and economic worlds, enabling the learner to make sensible estimates and be alert to the reasonableness of measurements and results. ***Figure 2.7*** below is a representation of the use of GeoGebra in teaching some aspects of Euclidean geometry.

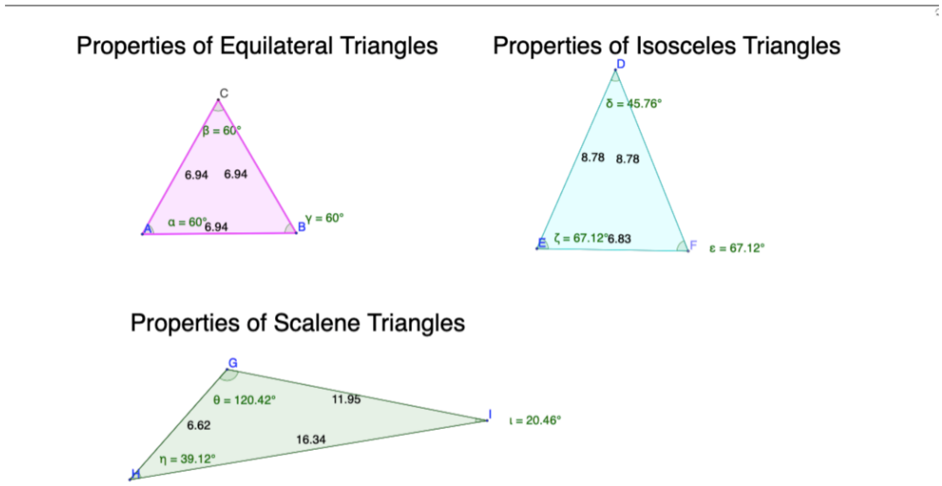


**Figure 2.7: Simulation showing the properties of different triangles (Choong & Hale, 2017)**

Venkataraman (2012) carried out a study in Singapore on the geometric reasoning skill in secondary school mathematics with GeoGebra software. It was found that learners taught with GeoGebra made progress towards mathematical explanations, which provides a foundation for further deductive reasoning in mathematics. It was also concluded that GeoGebra makes the learning of mathematics abstract concepts meaningful and helps learners to visualise related concepts. Moreover, other studies proved that the integration of GeoGebra in teaching, specifically geometry in mathematics, is positive and meaningful. Students who were taught geometry using GeoGebra showed improvement in their performance (Mosia, 2016; Stols, 2012).

The conclusion can be drawn that the integration of technology helps in creating a learning environment in which learners can discover, explore, conjecture and visualise.

#### 2.4.1.4 Probability and statistics and GeoGebra

Statistics involve asking questions and finding answers in order to describe events in the social, technological and economic environment. Through statistics, the learner develops the skills to collect, organise, represent, interpret, analyse and report data, as shown in ***Figure 2.8***. The study of probability enables the learner to develop skills and techniques for making informed predictions and describing randomness and uncertainty.

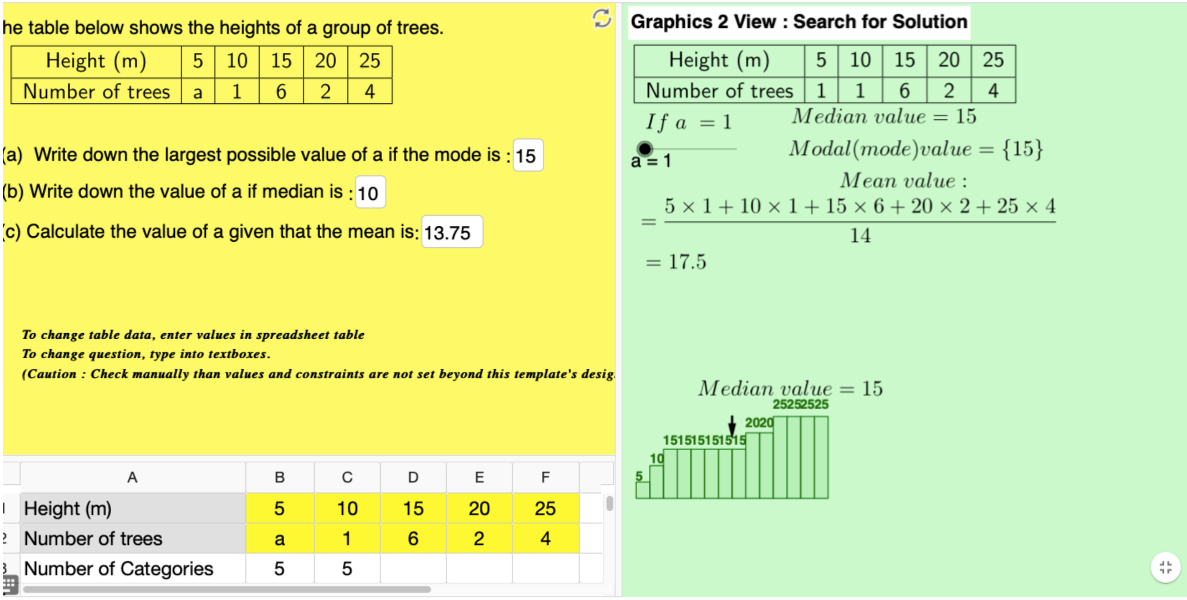


**Figure 2.8: Illustration of statistics work using GeoGebra software (Lewis, 2017)**

### 2.4.1.5 Trigonometry and GeoGebra

An experimental research study was conducted to identify the effect of integrating GeoGebra in the teaching of a subtopic of trigonometry functions and trigonometry graphs. The findings revealed that the integration of GeoGebra had a meaningful impact on learners who participated in the experimental group. As part of the literature review, it is important to evaluate the possibilities of how GeoGebra may be used in teaching a trigonometry concept.

Using a GeoGebra software under High School Functions (Trigonometry), a task is given as follows: Evaluate trigonometric functions of an angle given on its terminal ray (Brzezinski, 2017). As illustrated in ***Figure 2.9*** below for demonstrational and experimental purposes, Point P may be dragged wherever a teacher or learner chooses for [Min, Max] both coordinates equal to [10, 10].

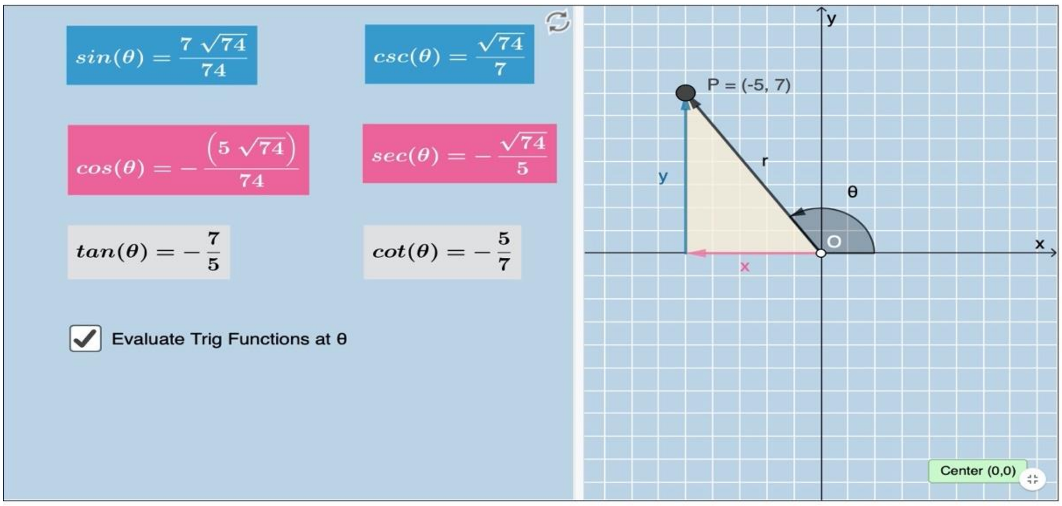


**Figure 2.9: Illustration of integration of trigonometric GeoGebra functions in teaching trigonometry**

## 2.5 Challenges and advantages of integrating ICT in mathematics learning

This section addresses the threats and challenges of integrating ICT in teaching mathematics. The literature relates to and views the challenges as perspectives and role models of how teachers can effectively integrate ICT tools in teaching mathematics.

According to Laurillard et al. (2012), there is a general acknowledgement of a positive relationship between education and technology in which tools and technology form an important aspect of education but the development thereof is seldom driven by education. In examining challenges from the early period of the introduction of ICT in teaching and learning, challenges have been identified from literature going back as far as 1999. Ertmer (1999) and Ertmer et al. (2012) classified the challenges into first and second-order barriers to ICT. First-order (external) barriers are challenges associated with access to and support for the use of technology. Second-order (internal) barriers relate to teachers' beliefs on how ICT could or should be used in teaching and learning.

These beliefs also include pedagogical beliefs and classroom technology practices. This classification has been a reference point for most researchers (e.g. Aslan & Zhu

2015; Brickell & Springer, 2016; Lim & Pannen, 2012; Msila, 2015; Yan et al., 2012) when they seek ways of effectively integrating ICT in teaching and learning.

The three reports from countries that have a good mathematics performance, as according to the TIMSS, seek to explore the first-order barriers to technology integration. In a case study from Indonesia, Lim et al. (2012) refer to the lack of funding and staff support. In a case study in China, Yan et al. (2012) highlight the acquisition of cutting-edge technologies in teacher education. In Cambodia, Dionys (2012) refers to the lack of digital resources and infrastructure as a response to the first-order barriers in the integration of ICT. Tsai and Chai (2012) identified an additional level of challenges in the integration of ICT in teaching and learning from the work of Ertmer (1999) and identified it as third-order challenges. Third-order challenges refer to the teachers' pedagogical strategies and how they improve their teaching practice with the involvement of technology.

Baya'a and Daher (2013) argue that teachers are a key factor in the integration of ICT. Teachers' perceptions of their ability to use ICT and their attitudes towards ICT contribute to their teaching of mathematics. Teachers' attitudes towards ICT contribute to learners' learning of mathematics as well as teachers' emotions towards the use of ICT in the mathematics classroom. Aguti (2016), Mwalongo (2011) and Tedla (2012) argue that teachers have the responsibility to promote creative and participatory learning to encourage the exchange of information. Ertmer and Ottenbreit-Leftwich (2010) concur that the challenges in the integration of technology revolve around teachers. They postulate that the challenges facing teachers in the integration of ICT in teaching and learning are a lack of relevant knowledge, low self-efficacy in technology use and conflicting pedagogical beliefs. These barriers explain why teachers could be reluctant to adopt ICT as an innovation in their teaching. Thus these barriers should be taken into consideration when teachers' adoption of such innovations is studied.

In the present research, I investigate these challenges in relation to the study of four mathematics high school teachers' integration of GeoGebra in teaching mathematics. GeoGebra exists within various ICT tools; hence it is important to discuss the challenges pertaining to the integration of ICT software, including GeoGebra.

## 2.6 Challenges and advantages of the integration of ICT software in mathematics learning

This study focuses on the integration of ICT software, specifically GeoGebra, in the teaching of mathematics in high school. Most teachers are noted to use ICT to prepare their teaching, and few teachers use it for enhancing their pedagogy (European Commission, 2013a). The challenges faced by teachers in the integration of ICT tools are discussed in this chapter. In a study by Mosia (2016) on improving teachers' TPACK for teaching Euclidean geometry using mathematics software, he made observations of the challenges facing teachers in the integration of ICT software in teaching mathematics. The challenges were teachers' negative attitude towards lesson preparation, teachers' workload and their access to versus quality of ICT. Assan and Thomas (2012) state that teachers' challenges in the integration of ICT software, specifically in the teaching of science and mathematics, are linked to their lack of training and skills to use these software tools. Magen-Nagar and Peled (2013) and Thomas and Palmer (2014) agree that school environments, resources and teachers are the main barriers preventing the implementation of technology in education. According to them, teachers' confidence, beliefs and attitudes towards the role of technology and towards the ability of successfully implementing it within schools are more profound as barriers. Furthermore, Suan (2014) is of the opinion that student performance and achievement are affected by teacher factors, learner factors and environmental factors.

Mdlongwa (2012) argues that the introduction of ICT in schools poses a major challenge insofar as ICT-based methods of teaching are being resisted by teachers due to their fear of change and lack of skills in incorporating the new ICT tools. Thus, when teachers lack the necessary skills or feel intimidated by ICT tools, they tend to abandon the software and miss the opportunity for creating learning activities.

Another challenge posed by the integration of mathematics software is the cost, accessibility of the software and the kind of learning activities that such software tools can bring to a learning environment. For example, HeyMath software is available for use in most schools in South Africa, especially in the Free State Province. HeyMath presents good fixed and animated lessons according to the South African curriculum. However, it does not allow for the teachers to create their own animated lessons. Other mathematics software systems, such as TI Interactive and CAS, are widely used in the United Kingdom, Australia and America. They are effective in helping learners to learn algebra. However, they are licenced software that is expensive; thus, access may be a challenge to many teachers and learners.

Teachers are a pivotal element of when and how ICT software tools are used in the mathematics classroom. Consequently, it is important that teachers are able to identify the strengths of different software programs and avoid using mathematics software if they have better ways of communicating the taught content (Koehler et al., 2014; Shafer, 2007). Integrating ICT software may lead to confusion if the lesson plan is not well structured.

## 2.7 PD in the teaching and learning of mathematics using ICT software

Research points to the teacher as the most important central factor in the integration of ICT and ICT software in the teaching environment (Xu, 2017). Watson (2015) is of the opinion that teachers may gain knowledge of the integration of technology through PD relating to technology integration. Education and school management are also believed to have a role to play in supporting teachers in order to present stimulating and informative mathematics lessons. This section explores the role of PD and how teachers are supported in the integration of ICT and ICT software in various parts of the world. Teacher PD should address the multiple forms of knowledge required for teaching. It should also involve the development of effective processes of knowledge management (Leask & Younie, 2013). Furthermore, it serves the purpose of addressing the multiple forms of knowledge required for teaching and involves the development of effective knowledge management processes (Leask et al., 2013). More studies have shown the potential of teacher PD that is tailored to local conditions as well as global components and takes advantage of mutual support among teachers and the modelling of effective practices (Albion et al., 2015). Teacher training courses, both pre- and in-service, can help teachers who are tentative to move faster and adopt technology, while they show more enthusiastic teachers new ways of implementing ICT in their profession (Abuhmaid, 2011).

Leask and Younie (2013) question why, if teacher quality is accepted as a critical factor in educational outcomes, so little attention is paid to improving the quality of teachers' professional knowledge. Approaches to extending the benefits of individual excellence include professional learning communities in schools, communities of practice and networks that enable sharing more widely on the Internet (Twining et al., 2013). The lack of attention to the PD of teachers in the integration of technology renders teachers reluctant to use technology in their teaching. There is, therefore, a need for the integration of technology to be accompanied by relevant PD (UNESCO, 2012).

Recent research has demonstrated the importance of local school factors on changes in teachers' pedagogical use of ICT. In a study with 1 076 teachers in 130 schools in Hong Kong, Li and Choi (2014) found that the positive effect of PD on teachers' pedagogical use of ICT was substantially less than the effect of social capital measured in two components. The first factor was the school climate and trust within the school, and the second factor was the existence of networks for accessing new information.

Other recent research in Cyprus indicates that, although teachers believe that using ICT can transform education and are willing to use it, little real change is occurring in schools (Vrasidas, 2014). The major barriers appear to be a lack of time, a lack of flexibility in the curriculum and a lack of access to ICT and support. Vrasidas (2014) notes that, although teacher PD needs to be systematic and systemic, it needs to be conducted in schools and respond to the local context. An international study on the implementation of interactive whiteboards confirmed the benefits of school-based teacher PD drawing upon the contribution of teachers (Hennessy & London, 2013).

Another study from a longitudinal intervention in seven primary schools in Australia concludes that the role of the ICT coordinator and school leadership in general can play a critical role in the success of PD (Tondeur et al., 2010). These findings support previous research on the importance of local conditions for the success of PD (Ertmer & Ottenbreit-Leftwich., 2013) and the benefits of networking teachers to share knowledge (Ertmer et al., 2012; Leask & Younie, 2013; Twining et al., 2013). Indeed, the integration of technology has been shown in several studies to have a positive impact on the teaching of mathematics. In addition, it is observed that teachers are an important aspect of ICT integration in the teaching of mathematics. According to UNESCO (2012), the role of the teacher is that of a facilitator with a responsibility to guide learners to achieve their educational goal. Consequently, their knowledge of ICT needs to be above and beyond that of their learners. Uche et al. (2016) concur that professional teacher development gives teachers an opportunity to interact with their peers and learn new skills and knowledge that are relevant to their 21st-century learning environment. An observation is made in Mofokeng and Mji (2010) that teachers are reluctant to integrate technology in their teaching. The study investigated teachers' use of computers in teaching mathematics and science in high school. The results of their study indicated that teachers cited the need to be trained as a key influence in their willingness to use ICT in their teaching. The implication was that education authorities should provide ICT training courses relevant to the South African education curriculum. Professional teacher development is an important part of teacher development and ensures success in the effective integration of mathematics software in the teaching of mathematics.

**Factors that have an impact on the PD of teachers in ICT integration**

The reluctance of most teachers to integrate ICT and mathematics software gives an indication that more has to be done to encourage them. Their reluctance also indicates that improving teachers' integration of ICT and ICT tools is not a straightforward task to be carried out in the education system. Abuhmaid (2011) identifies factors that have an influence on the effectiveness of ICT training courses when assigned for teachers. These factors include individual differences among teachers, school culture, teacher interaction and follow-up and ongoing support provided to teachers when they try to implement their newly developed skills. Education authorities need to pay attention to these factors so they could gain the confidence of teachers in the integration of ICT and various mathematics software in their teaching of mathematics.

The review of the literature on the integration of GeoGebra in the teaching of mathematics in South African schools has identified five major themes. The first examined the integration of GeoGebra within the South African high school curriculum. The South African curriculum is encapsulated within the CAPS document with elaborate mathematics mandated to be taught within a grade.

The next three themes make a distinction between ICT in general, ICT software and GeoGebra software. Most research studies are focused on the general integration of

ICT. However, there is a difference between ICT and ICT software. There is also a wide variety of mathematics software that may be integrated into the teaching of mathematics in South African schools. Therefore, the three themes of discussion make a distinction between ICT in general, ICT software and GeoGebra software as the software of choice within this study. Existing research has failed to present any distinction and focusing in particular on how teachers integrate GeoGebra software in the teaching of mathematics within a South African high school context.

From the literature, the teacher is acknowledged as the pivotal aspect of the integration of any form of software in teaching and learning. Therefore, the final theme incorporates a detailed discussion of the PD of teachers in the integration of mathematics software within a South African context.

## 2.8 Conceptual framework

Technological pedagogical content knowledge (TPCK) is the concept that encapsulates the integration of technology into the teaching and learning environment (Chai et al., 2013). It was originally known as TPCK; however, it is now called TPACK or technology, pedagogy and content knowledge (CK) (Koehler et al., 2013). TPCK, as it is originally known, is built on Shulman's (1987) descriptions of pedagogical content knowledge to describe how teachers' understanding of technology and pedagogical content knowledge interact with each other (Herbst & Kosko, 2014; Koehler et al., 2007). According to Shulman (1986), it is important to understand teacher knowledge in the context of understanding how CK and pedagogical knowledge relate to each other.

The notion of TPACK grew from the research done by Mishra and Koehler (2006) that emphasised the notion of the integration of technology in teaching and learning. According to Mishra et al. (2006), Shulman' work on pedagogical content knowledge (PCK) is not sufficient because teachers need to increase their understanding beyond content and pedagogy to include technology. The TPACK framework is labelled as teacher knowledge that is modelled into three knowledge components, namely content, pedagogy and technology. The interaction among these knowledge components demonstrates the type of knowledge that includes the integration of technology into teaching school subjects (Harris et al., 2009). The interaction among these knowledge components is illustrated in ***Figure 2.10*** below. TPACK is described as an amalgamation of knowledge that aims to integrate ICT into teaching and learning in any classroom. This interaction results in seven components included within the TPACK framework, namely technology knowledge (TK), CK, PCK, technological content knowledge (TCK), technological pedagogical knowledge (TPK) and TPACK (Schmidt et al., 2009). The dotted circle in ***Figure 2.10*** below acknowledges that the integration of ICT does not happen in isolation and represents the contextual factors that have an impact on the integration of ICT. The contextual factors include the environment in which learning with technology takes place (Spector et al., 2014).

Technology is now regarded as one of the teaching tools that are key to enhancing teaching and learning (Azlim et al., 2015). However, there is also a threatening view that in as much as the benefits of technology are acknowledged, the integration of technology remains a challenge to most teachers (Buabeng-Andoh, 2012). Kramarski and Michalsky (2010) postulate that teachers feel inadequately prepared for subject-specific integration of technology – they are aware of the importance of integrating technology, but when it comes to subjects such as mathematics, they are uncertain of the relevant ICT software to use for specific topics in mathematics. Hence, researchers are interested in designing a framework that guides how technology could be seamlessly integrated as a teaching tool.

According to Koehler et al. (2013), it is difficult to excel in teaching with technology. Hence, in ***Figure 2.10***, there is a dotted line that surrounds the knowledge domains and their interaction. The dotted lines represent teaching and learning in context because content, pedagogy, technology and the interaction between them do not exist in a vacuum. The interaction among these pillars of knowledge happens within an environment, which is the context from which learning with technology happens. Teaching efficaciously with technology needs relentless creation, maintenance and re-establishing a dynamic balance among all components (content, pedagogy, technology and the teaching and learning context) that have a role to play independently and together.

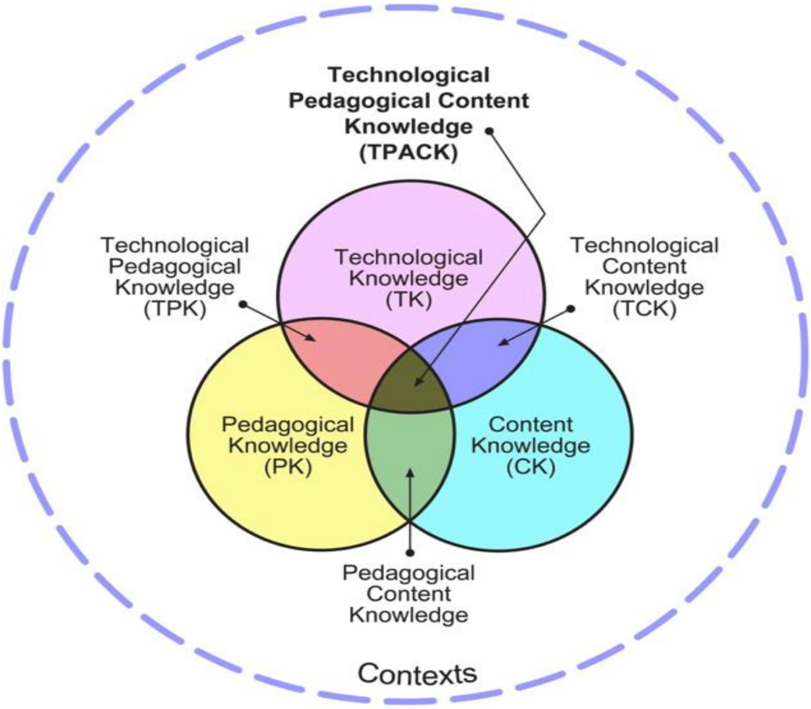


**Figure 2.10: The TPACK framework and its knowledge components (Chai et al., 2013)**

TPACK frameworks offer various ways of promoting research in teacher education, teachers' PD and the use of technology in a classroom environment.

> *[TPACK is] the basis effective teaching with technology which requires an understanding of concepts representation using technology; pedagogical techniques that use technologies in constructive ways to teach content, knowledge concepts difficult or easy to learn and how technology can help redress some of the problems (Koehler et al., 2013:16).*

This study seeks to engage teachers in their practices of integrating ICT software in teaching mathematics. In reaching this objective, the study seeks answers relating to teachers' knowledge of mathematics and how they teach it with the enhancement of technology. The study further investigates teacher development training that is relevant to the integration of ICT software. The study seeks to explore how teachers integrate GeoGebra in the teaching of mathematics in high school.

TPACK is relevant as a framework in giving the guideline of the measure of effective practices in the integration of technology in a teaching and learning environment. In order to answer research questions within this study, TPACK offers the measurement and assessment instrument with which to engage the practices of teachers in the integration of technology in the teaching environment as well as the approaches to PD relevant to the integration of technology.

The measurement and assessment instrument that is within the TPACK framework and relevant to answering research questions within this study is as follows (Koehler et al., 2013:17):

- Establish if participants agree to the use of technology in teaching.
- Allow participants to expand on their experiences with technology.
- Evaluate performance on specific tasks that assess TPACK.
- Interview participants to uncover evidence of their TPACK.
- Observe participants in the classroom for evidence of TPACK.

In this study, I also expand on the five measurement and assessment instruments in the evaluation of relevant ICT software used on specific tasks that assess TPACK. The study is focused on the integration of ICT software as opposed to ICT in general. Therefore, it is important that the specific use of ICT software is established within the framework.

### 2.8.1 Application of TPACK

This study also seeks to explore the teacher's effectiveness and approaches used in developing teachers' knowledge in the integration of technology with the policy guidelines and the rendered PD.

Koehler et al. (2013) and Mishra and Koehler (2006) are of the view that **teachers' effectiveness** needs to be related to their ability to synchronise their TK, PK, and CK. This is set out as follows:

- TK gives teachers an understanding of how to operate technologies that are available for teaching and learning.
- PK brings to light teachers' understanding of the different teaching strategies that exist in the teaching and learning of a particular subject. Koehler et al. (2013:15) describe it as a "generic form of knowledge that applies to understanding of how students learn, general classroom management skills, lesson planning and student assessment", thereby demonstrating the understanding of the necessary conditions for the process involved in learning and common approaches to and methods of teaching.

- Koehler et al. (2013) describe CK as teachers' knowledge about the subject matter to be learnt or taught, for example knowledge of mathematics to be taught in a particular grade or level of education. CK also describes teachers' level of understanding of how the subcomponents of the subject matter are interrelated. It is important for the teacher to have in-depth knowledge of the subject area (Mishra & Koehler, 2006). CK is one of the knowledge components that is linked to PCK and TCK.

Three approaches have been proposed for **teachers' development of TPACK** (Koehler *et al*., 2013:17), namely:

- PCK to TPACK: Teachers use their existing PCK to make decisions about which technology is relevant for the lesson outcome.
- TPK to TPACK: Teachers generally build their TK so that they are efficient in using technology. They then use this acquired knowledge to identify and develop lessons that are beneficial in teaching with technology. For this study, it is important that teachers develop TK that allows them to search for various ICT software programs that are relevant to teaching specific topics.
- Developing PCK and TPACK simultaneously: Teachers gain experience and knowledge through projects that require them to define, design and refine solutions for learning problems and scenarios. These activities produce insight into various ways of interaction between content, pedagogy and technology as a new form of teacher knowledge.

The TPACK framework is relevant for this study because it provides the means to measure and map out how teachers integrate GeoGebra in teaching mathematics in high school in terms of the different knowledge components. In this study, the TK of TPACK as the framework refers to the TK of the tools that are relevant when a teacher uses GeoGebra or any mathematics software in their teaching. It also allows researchers to make sense of the integration of these components into teaching. It further gives guidelines to the relevant PD appropriate for the integration of technology.

This study uses interpretivism as the paradigm within this study. In this study as interpretivist research, it is important to explain or understand how teachers experience and interpret the phenomenon of the integration of ICT software in their material setting, which is their classroom (cf. Howson, 2013). It is therefore important to consider a framework that unveils the views and experiences of the participants. TPACK is widely used in research that seeks to engage the use of technology in a learning environment.

According to Baran et al. (2011), the “TPACK framework has provided the means for educational technology researchers and practitioners to communicate more accurately and effectively about the work they are doing”. TPACK is imperative in giving the ability to test practices in teaching approaches involving technology and is widely used in research similar to this study. Koehler et al. (2012) mention that interviews, observations and open-ended questionnaires are used to measure TPACK. In So and Kim’s (2009) study, participants were asked to give their written views on the integration of technology. Their responses were later coded using TPACK as a guide. In the study of Niess et al. (2009), teachers were interviewed in unstructured interviews on the advantages and disadvantages of the use of various ICT tools and the effect thereof on teaching and learning. The study used observation, and the information was later transcribed and coded using TPACK as the guideline. Furthermore, in studies by An and Shin (2010), Banas (2010), Mouza et al. (2014) and Wilson and Wright (2010), case studies were used for participants to reflect on their ideas about, beliefs on and experiences of the integration of ICT and ICT tools in the teaching of mathematics.

When there is an introduction of any teaching resource, including technology, there is also a need for PD to help teachers with skills and knowledge. According to Koehler (2013), TPACK helps to determine the impact of interventions and PD programme and to understand the current state of teachers’ knowledge domain. This study seeks to explore how teachers integrate GeoGebra in the teaching of mathematics. In order to gain that understanding, TPACK as a framework will assist in asking relevant questions and making informed observations and analyses. Hence, TPACK is the relevant framework to help answer the main research question in the study.

## 2.9 Summary

The chapter presented a discussion of the related literature on the integration of GeoGebra and related ICT hardware and software tools in the teaching of mathematics. The discussion of the literature revealed different scholarly views that

ICT has become an integral aspect of modern society. The integration of ICT stretches from everyday, normal use to the education environment, especially in mathematics education. The literature review further deliberated that ICT and ICT software have made a positive contribution in the learning environment. However, the success of ICT integration is dependent on teachers and the other factors that are linked to making any learning environment a success. Hence, there were detailed deliberations in pedagogical strategies, with the inclusion of ICT tools and impeding factors with the integration of technology. The discussions also included the success in the integration of ICT and GeoGebra internationally and in South Africa. Some countries have included GeoGebra into their curriculum. South Africa, on the other hand, is making strides in the integration of ICT and ICT software through the provision of equipment and the professional development of teachers. The literature review further explored the South African high school curriculum and how GeoGebra may be used to enhance understanding of those content areas.

The conceptual framework underpinning the study was discussed, together with its relevance to the study.

# CHAPTER 3: RESEARCH METHODOLOGY

## 3.1 Introduction

In Chapter 3, I seek to describe, justify and discuss the research methodology of the study, which includes the research paradigm, approach and selected design that are appropriate to the aims and objectives of the study as well as the description of the chosen participants. The philosophical view that has been chosen for this study and the justification of the qualitative research and the methods and procedures of data collection are also discussed in detail to build an understanding of how teachers integrate GeoGebra in the teaching of mathematics in South African high schools. Credibility and trustworthiness, including ethical factors, are also considered to ensure that the results of this study are accepted as a meaningful contribution to the body of knowledge to be used by other researchers. In order to guide the study, the following critical research questions are addressed:

- What are teachers' perceptions of the integration of GeoGebra in the teaching of mathematics in South African high schools?
- What are teachers' practices in the integration of GeoGebra in the teaching of mathematics in South African high schools?
- What kind of professional development (PD) (if any) is provided to teachers in teaching mathematics using the GeoGebra software in South African high schools?
- How can we account for teachers' understanding of and practices in the integration of GeoGebra to teach mathematics in South African high schools?

## 3.2 Research paradigm

The word "paradigm" became known from the work of an American philosopher called Thomas Kuhn in his book *The Structure of Scientific Revolutions* (1962). Kuhn used the word "paradigm" to refer to the philosophical way of thinking. Kuhn challenged the way mankind thinks about and understands the world (Horgan, 2012).

In education, the word "paradigm" is used to describe a worldview. According to Kivunja and Kuyini (2017:26), a worldview "is the perspective, or thinking, or school of thought, or set of shared beliefs which informs the meaning or interpretation of research data". Paradigm also refers to views we hold of the world we live in and the meaning we attach to them. Babbie (2010) concurs that paradigm generally refers to a frame of reference to give meaning to observation and reasoning. From a researcher's point of view, De Vos et al. (2011) describe a paradigm as a consistently legitimised assumption and design for the collection and interpretation of data.

Interpretivism stands in contrast to positivism and maintains that there are multiple truths and various forms of realities because external reality varies according to the individual's perception of it, while positivists posit that there is only one truth or reality (Creswell, 2007). Interpretivism is an approach where individuals seek to understand their world by providing participants with opportunities to share their experiences, views and opinions (Creswell, 2007; Thanh & Thanh, 2015).

This study is aligned with the interpretivist methodological paradigm because it seeks to investigate how teachers integrate GeoGebra in teaching mathematics in South African high schools from their own experiences. Interpretivism is structured through the interpretation of human experiences obtained by way of observation and experiments (Thomas, 2010). Interpretivism is based on the principle that the focus of the researcher is on understanding the meaning and interpretations of participants from their perspectives (Goldkuhl, 2012). Through the use of semi-structured interviews and class observations, I managed to facilitate a subjective relationship with the participants whereby I sought to understand the integration of GeoGebra from their perspective.

Thanh and Thanh (2015) postulate that interpretivists consider multiple realities gained from participants' interpretation of the situation. Furthermore, they aim to work alongside others as they seek to understand and draw meaning from the situation, create their realities in order to understand their point of view and interpret these experiences within the context of the researcher's academic experience (Creswell, 2014). Interpretivists similarly consider it important to understand what people are thinking and feeling as well as how they communicate, both verbally and non-verbally. My focus was to understand the meaning and interpretations of participants from their own perspectives (cf. Goldkuhl, 2012).

This study used the interpretivism paradigm that requires the gathering of the data in such a way that the researcher is able to understand the world from the multiple interpretations of the viewpoint of the participants (cf. Howson, 2013). Their multiple interpretation created a social reality in which education stakeholders can gain an understanding of the integration of GeoGebra and other software in the teaching of high school mathematics. Hence, it was imperative to discover and understand these various interpretations and circumstantial factors as experienced by different mathematics teachers who were using GeoGebra in teaching mathematics in high school. A study within interpretivism as a paradigm helped me to gather in-depth information because the participants freely expressed their views, knowing that their shared information was confidential.

## 3.3 Research approach

This is a qualitative study on how teachers integrate GeoGebra in the teaching of mathematics in South African high schools. Qualitative research is broadly known as a methodology to gain insight into individuals' knowledge, attitudes, behaviour, views, perceptions and motivational aspiration through the collection of information. The information is collected through interviews and the analysis of textual and visual content (Howson, 2017). Similarly, such a research approach offers numerous gains for my study. The examples of topics that qualitative methodologies seek to address relate to individuals' experiences, perspectives and how these experiences, attitudes and environments influence their behaviour (Rule & John, 2011). A qualitative approach is known to focus on non-numerical data and the research information or data that are gathered from occurring phenomena.

In this study, I was particularly interested in exploring how teachers integrated GeoGebra in their teaching of mathematics. Furthermore, I was predominantly interested in their experiences, views and the meaning they ascribed to these experiences. The *GeoGebra Software Manual* and ICT training documents provided a context in which the teachers' construction of perception and meaning could be described and then interpreted. To explore the perspectives and perceptions of teachers on the integration of GeoGebra, a qualitative methodological approach was employed. The qualitative approach has been particularly suitable for this study, as I unveiled the meaning of a phenomenon by using the views, perceptions and experiences of the participants (cf. Maree, 2012; McMillan & Schumacher, 2010).

Qualitative research methods are concerned with understanding human thoughts and behaviour with emphasis on the meaning they attach to their actions (Okeke & Van Wyk, 2016). This research approach allowed me to gain an understanding of what high school mathematics teachers thought of the integration of GeoGebra software in the teaching of mathematics within a South African context. Moreover, through this research approach, I was able to observe and gain their understanding of ICT tools, ICT software in general and, most importantly, GeoGebra software. Furthermore, I was able to gain an understanding of their PCK and CK of mathematics and their practices in how they integrated GeoGebra in teaching the same content.

Through the qualitative research approach, I explored the understanding of the teachers' perception in their PD in strengthening their skills and knowledge in the integration of GeoGebra. Flick (2015) argues that the qualitative method provides insight into humans' interpretation of their own experiences, which is difficult to achieve through other methods. I collected detailed stories of teachers on how they integrated GeoGebra in the teaching of mathematics in high school.

According to Ritchie et al. (2013), the qualitative research approach allows the researcher to engage with participants through interviews, observations and analyses of documents as is required of the qualitative research approach. In this study, data were collected through document analysis, semi-structured interviews and non-participatory observation. For the document analysis, I undertook an analysis of the *GeoGebra training manual*, policy relating to e-learning and the PD of teachers in the integration of technology. The research involved semi-structured interviews and class observations of four mathematics teachers who teach mathematics in South African high schools within the North-West Province. McMillan and Schumacher (2010) postulate that qualitative research is focused on exploring and understanding a particular phenomenon through the views and practices of the participants, especially in the education environment. Through the interviews and observation, I was able to explore the teachers' views and practices in their teaching environment.

There is limited information about teachers' experiences of and views on how they integrate GeoGebra in their teaching of mathematics. This study intertwines the existing research in the integration of ICT and ICT software in the teaching of mathematics and teachers' views on how they integrate GeoGebra. The selected teachers received training in the integration of GeoGebra and have, since then, started using GeoGebra in their teaching of mathematics. The lived experience of the selected teachers who were using GeoGebra in their teaching of mathematics is the basis from which the data for my research emerged. It is through these teachers' lived experiences and views that I gained insight into the integration of GeoGebra and how such information may be used in the integration of other mathematics software (cf. Zakaria & Lee, 2012).

Along the same thought process, the qualitative research approach was employed because the study sought to gain insight into the experiences (understanding and practices) of high school teachers in the integration of GeoGebra in teaching mathematics in South African schools by gaining an understanding of their ideas, perceptions and motivation.

## 3.4 Research design

A research design is described as a means from which all aspects involved in identifying the problem through reporting and publishing the results are executed in a research study (Punch, 2013). The research design serves as a plan of action from which the study is communicated. It is an important aspect of the research process because it is a guiding tool for the researcher for the analysis and reporting of the findings of the study. The role of the researcher in qualitative research is described as the individual who attempts to access the thoughts of the selected participants, which can assist in gaining an understanding of their interpretation of their experiences.

In this research, I used a case study as the research design. According to Creswell (2014:14), a case study is a "design of inquiry … in which the researcher develops an in-depth analysis of a case, often a program, event, activity, process, or one or more individuals". I considered in detail the cases of four teachers, each as a separate case, and made an intra-case analysis. Punch (2011) maintains that the case study is an empirical research method that investigates the phenomenon within its real-life setting and relies on multiple sources of evidence. I, therefore, considered the stories of the four participating teachers as separate entities and cross-examined their stories in search of commonalities and differences.

In this research, the case study is an in-depth examination of the extensive involvement of teachers who are integrating the GeoGebra software in their teaching and learning at high school level. Arguing in favour of the case study design, Rule and Vaughn (2011:7) suggest that the rationale for using the case study design is not only to provide a “thick, rich description of the case under investigation. Moreover, the case study sheds light on other similar cases, hence providing a level of generalisation that makes case studies more relevant to the study. Using the case study design, I observed common and deviating perceptions on and practices of how teachers integrate GeoGebra in the teaching of mathematics in South African high schools. I understood the challenges that the teachers had in integrating GeoGebra and the need to strengthen their PD to improve their skills and knowledge in the integration of GeoGebra and other mathematics software.

According to Xu (2017), teachers should be viewed as agents of technology integration. Without the involvement and commitment of teachers in integrating technology, the integration of technology in mathematics classrooms will not be realised. A case study focuses on participants’ views on and experiences of a particular issue within its context. A case study may range from individuals, schools and communities to countries (Rule & John, 2011). Four high school mathematics teachers from different schools were studied as cases. Cohen et al. (2013) further explain that in a case study, the context is unique and vibrant; thus each case investigates and reports the real-life experiences of individuals, unfolding the interaction of events, human relationships and other factors in a unique situation. I was thus exposed to different perceptions from different teachers, different schools and classroom contexts of the four selected teachers and explored how they integrated GeoGebra in their teaching. I sought to understand from the teachers’ opinions the teaching of mathematics using ICT tools, ICT software and GeoGebra, in particular, in a South African high school context. I explored the teachers’ views on their PD in the integration of GeoGebra.

In this case study, I explored and analysed the perceptions that different teachers attach to GeoGebra and the practices that relate to the integration of GeoGebra. Interviewing and observing each teacher as a case study, several times over a prolonged period, awarded me the exposure to experience different dialogues in different settings and unique classroom environments with the mathematics teachers on their experiences of integrating GeoGebra in a South African high school context. According to Bertram and Christiansen (2014), case studies are descriptive in nature, aim to give a description of what it is like to be in a situation and are used to generate claims for further verification. Magwa and Magwa (2015) add that case studies involve studying individuals in their own territory and engaging with them on their own terms so as to generalise about the wider population. My study allowed teachers to tell their stories in their own terms while I was interacting with them with no minimum interference in observing how they taught mathematics with GeoGebra. This, in turn, gave a perspective about the integration of GeoGebra and other mathematics software in teaching mathematics within a South African high school context.

During the fieldwork of this study, I was an essential component of the data collection instruments and procedures. Through my personal involvement in the data collection, I was able to listen and see for myself how teachers integrate GeoGebra in the teaching of high school mathematics in a South African context. I was also able to understand their views on their PD to strengthen their skills and knowledge on how they teach a high school mathematics South African curriculum with GeoGebra. In this case study, I studied each of the four teachers over a 10-week period. My prolonged stay in the field was intended to gather authentic data and yield credible findings that may be transferable to similar situations.

The case study design is generally criticised for being limited to generalisation based on an individual case (Starman, 2013). In studying the four teachers who share the common experience of teaching high school mathematics using GeoGebra, I maintained a sample size, thereby increasing the trustworthiness of the collected data and maintaining transferability of the findings under similar situations.

Ponelis (2015) also criticises the case study as a research design by pointing out the researcher is the primary data collection instrument and researchers tend to have bias. I therefore minimised my personal bias, firstly, by engaging the e-learning directorate of the North-West DoE to consider schools where the teachers have received training on the integration of GeoGebra. I visited three schools in the province to establish the teachers' engagement with GeoGebra in their mathematics teaching. I minimised my personal bias by setting the criteria to choose the participating teachers and immersing myself in the research site during the participant selection and data collection. I visited the schools several times and communicated with the teachers telephonically for further clarification and making sure of the validity of the collected data. I audio recorded the interviews and video recorded the observed class lessons. Reflective field notes, data triangulation and a pilot study were also employed to reduce personal bias and for me to remain objective in this study.

My research explored how teachers integrated GeoGebra in the teaching of mathematics in South African high schools. Specifically, it examined the perceptions, practices and PD of teachers in their integration of GeoGebra in a South African curriculum context. The phenomenon of the integration of ICT tools, specifically GeoGebra as mathematics software, forms the basic unit of analysis in this study. Therefore, the case study design was appropriate for the study because it helped me to examine the teachers' perceptions and practices of and views on the training they were exposed to in the integration of GeoGebra in teaching high school mathematics.

## 3.5 Sampling procedure

Sampling is the process of selecting a few representatives that are referred to as the "sample" from a bigger group called the "sampling population"; the sample then becomes the basis from which the outcome of the study is predicted (Okeke & Van Wyk, 2016). In qualitative research, sampling is described as the process of selecting a few individuals or informants selected on the basis of their experience or knowledge of the topic under study. A small number of individuals are selected and studied intensively (Cleary et al., 2014).

For this qualitative study, semi-structured interviews and non-participatory class observations were conducted with the selected individuals based on purposive sampling. Rule et al. (2011) describe purposive sampling as a method where individuals are specifically picked as research participants because of the skills and knowledge they possess that are relevant for the purpose of the research. I used a purposively selected sample consisting of mathematics teachers who had received training in GeoGebra integration and used GeoGebra in teaching mathematics. My choice of teachers was measured and I made a specific judgement in selecting the particular participants for the study (cf. Etikan et al., 2015). My decision was based on what needs to be known, that is, the perceptions and experiences of teachers in the integration of GeoGebra. The selected participants were therefore selected based on their skills in teaching mathematics with GeoGebra, which is in accordance with the objective of the study.

I selected three high school mathematics teachers from schools within the Bojanala district in Rustenburg. The selection was based on the teachers' experience, access to computers and the Internet and already using GeoGebra software in teaching mathematics in high school, in particular at the FET level. FET includes the last three years of high school in the South African education system. The map below illustrates the district in which the three schools are located.

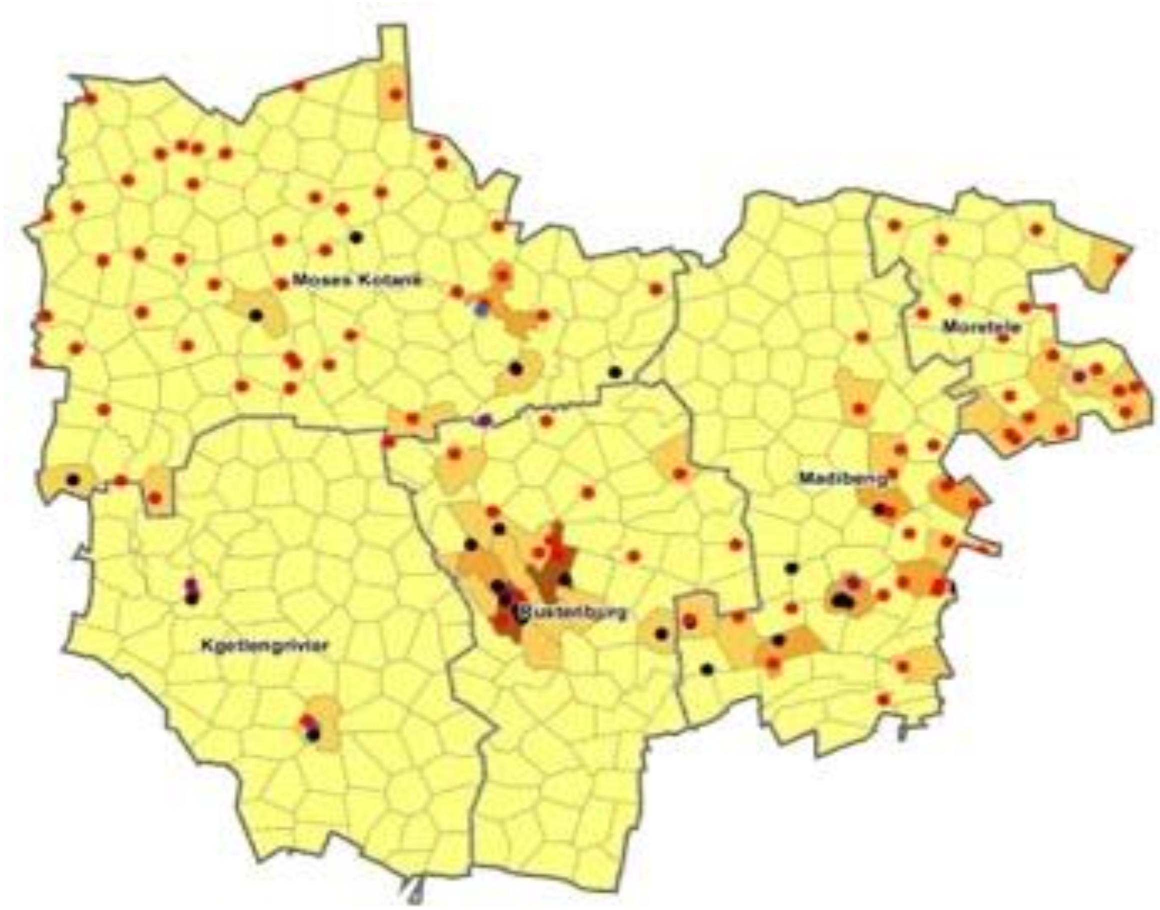


**Figure 3.11: Map of research site – Bojanala district**

As part of the sampling process, I visited different schools from the Bojanala district, conducted interviews with teachers and observed the ICT tools they used in their teaching and learning. ***Figure 3.1*** is a map of the location of the Bojanala district. From various teachers in the Bojanala district, I purposively selected teachers that met the set criteria. Purposive sampling gave me the advantage of recruiting teachers with the skills and knowledge that I needed for my study (cf. Creswell, 2015). I also studied the e-learning policy and framework as well as the *GeoGebra Software Manual* for document analysis and as a means of strengthening my data and triangulating the findings.

Yin (2014) is of the opinion that purposive sampling aims to help the researcher answer the research question. In this study, I sought to answer the main research question: How do teachers integrate GeoGebra in the teaching of mathematics in South African high schools? Purposive sampling allowed me to select teachers whose valuable knowledge, experience and perceptions allowed me to gain information to answer the said research question.

## 3.6 Data collection strategies

In research, the word “data” refers to the information collected by the researcher, which, after being collected, will be interpreted with recommendations and conclusions drawn from the data (Sutton & Austin, 2015). Kumar (2014) argues that the value of qualitative research lies in the researcher’s skill to provide textual stories of participants of their view of the given research study. In my study, I used semi-structured interviews, observations and document analysis as the data collection instruments to answer the critical questions raised in the study. Below in ***Table 3.1*** is the data collection plan that I used to collect data.

**Table 3.1: Data collection plan**

| Research question | Participants | Data collection method |
|---|---|---|
| 1. What are teachers’ perceptions of the integration of GeoGebra in the teaching of mathematics in | Teachers | • Semi-structured interview<br>• Observation of a taught lesson |

| Research question | Participants | Data collection method |
|---|---|---|
| South African high schools? | | |
| 2. What are teachers' practices in the integration of GeoGebra in the teaching of mathematics in South African high schools? | Teachers | • Semi-structured interview<br>• Observation of a taught lesson<br>• Document analysis: Analysis of the lesson plan, activities and assessments used as part of teaching and learning when GeoGebra is an integral part of the lesson. |
| 3. What kind of PD (if any) is provided to teachers in teaching mathematics using GeoGebra in South African high schools? | Teachers | • Semi-structured interview<br>• Document analysis: Policy and workshop material relating to the integration of GeoGebra |
| 4. How can we account for teachers' understanding of and practices in the integration of GeoGebra to teach mathematics in | Teachers | • Semi-structured interview<br>• Observation of a taught lesson<br>• Document analysis: Analysis of the policy on e-learning and available training material |

| Research question | Participants | Data collection method |
|---|---|---|
| South African high schools? | | |

The observations and document analysis were guided by the formulated checklist that is guided by the aim of the study (cf. Bengtsson, 2016). The observations were non-participatory. The teacher and the learners were made aware of my role, and I sat at the back of the class for minimal obstruction (cf. Rule et al., 2011). The lesson plan and material that were received as part of the training in the integration of GeoGebra formed part of the documents I analysed.

### 3.6.1 Semi-structured interviews

Howson (2013) postulates that semi-structured interviews are used in qualitative research as the means to gather information from people about their attitudes, beliefs and feelings about the topic that is relevant in the study. Semi-structured interviews further encourage participants to talk freely in their own words about the research topic and even talk about issues that the researcher may not have considered but may be vital for understanding the phenomenon under study. The semi-structured interview is common in qualitative research because it allows the freedom to explore topics and the researcher can follow up on questions with little restriction.

In my study, the interviews were formally planned in advance, with a business-like atmosphere for me to gain the respect and cooperation of the participants. The interviews were scheduled for one hour. The interview questions were of a flexible format and prepared prior to the scheduled interview, in accordance with Walliman's (2017) suggestions. During the interviews, rapport was established with the participants (cf. Smith 2015). This allowed the participants to be at ease and to speak freely about their understanding of and practices in the teaching of mathematics in general and elaborate on the integration of ICT tools and GeoGebra.

Three planned semi-structured interviews were held with each mathematics teacher studied as a case in this study. All the interviews were recorded with an audio recorder and later transcribed. The interviews were in the form of semi-structured interviews that ranged from 40 to 60 minutes and were guided by the interview protocol (***Appendix A***). These interviews were followed by other telephonic interviews for clarification or additional information emanating from the semi-structured interviews.

The semi-structured interviews were relevant for this study because they assisted in answering the research questions about the teachers' understanding and interpretation of the e-learning policy and their views on their theoretical understanding of the integration of the GeoGebra software. In answering these questions, I needed the freedom to ask as many questions as necessary to obtain detailed information if the participants did not provide enough information. I could also clarify any ambiguity in the questions.

To ensure that the interviews were focused and engaging, I prepared interview protocols (***Appendix A***) to guide the interviews held with each participating teacher. Rubin and Rubin (2011) postulate that a researcher should use three types of questions in a research interview, namely the main question, follow-up questions and probing questions. In this study, I followed their advice as I posed the main question and used follow-up and probing questions to elicit more details, examples and clarifications on the discussed issues.

### 3.6.2 Non-participatory observation

Lesson observation was the second data collection strategy I used to gather data on how teachers integrate GeoGebra in their teaching of mathematics in South African high schools. Walliman (2017) views observation as part of data collection, where the researcher records what he or she sees, reads and hears, as opposed to relying solely on what he or she is being told by the participants. Furthermore, Magwa and Magwa (2015) describe observation as the data collection process where observed behaviour and interaction take place but are understood through the eyes of the researcher. I formulated the observation protocol (***Appendix B***) that I used to record my observation. Later, I categorised the data collected into themes that helped to answer the research questions raised in the study. The observation was guided by the pillars of knowledge as identified in the conceptual framework. I observed the relevant attitudes, skills and teaching strategies of the teachers as well as the learners' reactions to how they were being taught within the TPACK framework (cf. Harris et al., 2011). The observational rubric or protocol encapsulated the pre- and post-observation protocol with a description of the content of the lesson, a description of the learners in terms of their grades and specific learners' needs and a description of how technology would be incorporated in the lesson.

The pre-observation interview protocol (***Appendix B***) was held with each mathematics teacher before the start of the non-participatory class observation lesson that was conducted with GeoGebra. During this interview, I sought to understand the grade that was to be taught, the planned content, expected misconceptions, the planned assessment during the lesson and the planning of using GeoGebra and related ICT tools in conducting the lesson. This was followed by a post-observation interview protocol (***Appendix B***), which was held at the end of the non-participatory observation lesson. This interview sought to understand the teachers' reflection on how the lesson went and whether the lesson was executed according to their plan. The pre- and post-observation lessons ranged from 10 to 15 minutes. Cohen et al. (2011:411) argue that "[b]y providing access to what is inside the person's head, an interview makes it possible to measure what a person knows … and what a person likes or dislikes … and what a person thinks". I therefore used the interviews to gain insight into the teachers' understanding of and views on how they integrate GeoGebra in their teaching of mathematics within a South African context.

I used the non-participatory observation technique, which awarded me an opportunity to observe how the teachers integrated GeoGebra in their teaching of mathematics without interfering with the ongoing teaching in class. I focused my attention on knowledge and skills relating to the use of GeoGebra and the GeoGebra software itself. I observed how the lesson unfolded while noting down the taught content, the introduction of the lesson and how the teacher related the concept to GeoGebra while also maintaining the learning culture in the classroom. I video recorded detailed descriptions of the activities and practices that I observed, while also recording data as part of my field notes. This was done in line with guidelines provided by Okeke and Van Wyk (2016:286) – "Data from observations are recorded in the form of field notes. It is imperative that as a qualitative researcher you keep a field notebook in which to record daily notes." I transcribed and organised my observations using the formulated class observation protocol after the lesson. The observation field notes and recorded videos were coded into themes and sub-themes for analysis and interpretation.

Non-participatory lesson observation was conducted at all three schools. I arranged the class observation visits in advance. The teachers invited me to observe lessons for the content that they had planned to teach using GeoGebra.

### 3.6.3 Document analysis

Document analysis is an important data collection instrument in a case study, especially if the research design includes interviews or observation (Rule et al., 2011). The documents in a case study usually include written reports or documents relevant to that particular phenomenon (Owen, 2014). The use of document analysis is considered to be ideal in situations where some aspects of the research have not been addressed appropriately by other methods of inquiry. In this study, the scrutinised documents included lesson plans, *Guidelines for Teacher Training and Professional Development in ICT* (DBE, 2007), *Guidelines for Schools: ICT Hardware Specifications* (DBE, 2012), the *White Paper on e-Education* and the *GeoGebra Software Manual*. Document analysis provided me with the official information of what the teachers were exposed to regarding the integration of GeoGebra in South African high schools. Furthermore, I was able to understand some information that was communicated during the interviews, which also put into perspective some behaviour that was observed during the class observation (cf. Briggs et al., 2012). I triangulated the document analysis, interviews and class observation in the study. This helped me to confirm or disagree with some views about the integration of ICT and ICT software in the teaching of mathematics.

According to Creswell (2014), during qualitative research, a researcher may collect qualitative documents, which may include public documents. This is to assist the researcher in gaining an unobstructed source of information in order to gain a contextual understanding of the participants' views and experiences. I examined the *Guidelines for Teacher Training and Professional Development in ICT* (2007) that the DoE in South Africa uses as a guide at the district level for the development of teachers in the integration of all technology, including GeoGebra. The guideline document is also supported by a policy document (*White Paper on e-Education*) that explains the objectives, funding and implementation strategies of ICT-related teaching and learning. A lesson plan was an important document that gave perspective to the teachers' understanding of the content and their implementation strategy in class.

Schools and the South African DoE district offices are the custodians of the analysed documents. The teachers and the e-learning district official provided me with the documents, which I analysed. I used the documents to gain a perspective of the ICT tools that teachers were exposed to and the kind of training that they were envisaged to have.

## 3.7 Data analysis

Data were obtained from documents, interviews and observations and recorded electronically using voice and video recorders with the permission of the participants. For the data analysis, I listened to the recorded information several times and transcribed it. According to Howson (2013), in qualitative research, the data analysis process commences with the data collection phase and continues through the fieldwork until the report is produced. I started the data interpretation phase and analysis by listening to the recorded information several times and then transcribing it. I then looked for patterns of views, practices and emerging themes and classified these into meaningful categories that could be coded. The transcribed data were then coded accordingly in order to categorise the data and to identify patterns. Howson (2013) and Ritchie et al. (2013) state that coding is a part of qualitative analysis that allows the researcher an opportunity to categorise and analyse the collected data.

> *Coding refers to the identification of topics, issues, similarities, and differences that are revealed through the participants' narratives and interpreted by the researcher. This process enables the researcher to begin to understand the world from each participants' perspective. (Sutton & Austin, 2015:228)*

The data analysis techniques that I used included content analysis. Content analysis is a reflective process of analysing data in qualitative research (Erlingsson & Brysiewicz, 2017). The data obtained from the four mathematics teachers through semi-structured interviews, observations and document analysis were analysed. The steps followed in the content analysis were recorded according to the three steps proposed by Erlingsson et al. (2017). The initial step was to read the data thoroughly and then transcribe the data while keeping in mind the aim of the study. During this phase, it was important to divide the text into small and meaningful units. The second step was to code the meaningful units. These codes were helpful in reflecting on the data in new ways. The final step was to group the codes into categories or themes. Sutton et al. (2015) refer to theming as the drawing together of codes from different transcripts of participants in order to present the findings of qualitative research in a coherent and meaningful manner.

## 3.8 Credibility and trustworthiness

Trustworthiness of qualitative research can be achieved through triangulation, member checking, detailed transcription, a well-executed plan and coding (Gunawan, 2015). Furthermore, the researcher needs to pay special attention to the selection of cases and have comprehensive observational and analytical capabilities (Mills & Birks, 2014).

In this study, measures taken to ensure trustworthiness included my visits to the participants to develop rapport with them. This allowed me an opportunity to build a relationship of trust and to gain confidence in their knowledge and skills in participating in this study. This was followed by the final selection of the research participants who would provide suitable data to answer the research questions, member checking and triangulation in order to support findings with information from the obtained literature. I ensured the credibility of this research through considering the limitations of the study, which included the selection of the participants within one province although the research sought to explore the integration of GeoGebra within a South African high school context. To this end, I considered the fact that mathematical concepts are the same throughout the entire country; therefore, the experiences and views of the selected teachers are transferable. Following the advice of Gay, Mills and Airasian (2012), I emphasised transferability by including statements that are familiar to mathematics teachers in order to make it easier for the readers of the study.

According to Bloomberg and Volpe (2008), the credibility of a study refers to how the researcher portrays the participants, their views, practices and attitudes and whether he or she is in agreement with the participants' perceptions. In this study, I recorded the interviews and transcribed these, which I later sent via email to the participants for them to check the correctness of the recordings and transcriptions. Furthermore, I used triangulation, member checking and prolonged engagement to ensure the credibility, reliability and trustworthiness of the research.

### 3.8.1 Triangulation

Triangulation, which Kumar (2014) also refers to as crystallisation, is an approach that allows the use of a combination of more than one research strategy in collecting data in order to enhance confidence in the subsequent findings (De Vos et al., 2011). Furthermore, triangulation helps the researcher to reduce bias, as it cross-examines the integrity of the participants. The researcher cross-refers the answers of the participants from the selected research instruments (Anney, 2014). I used document analysis, semi-structured interviews and lesson observation as instruments for collecting the data for this research; this allowed me to explore the integration of GeoGebra from different angles. I could explain the participants' views and perceived challenges in the integration of GeoGebra in a high school mathematics classroom. Data triangulation made it possible for me to study the policy, framework and GeoGebra manual, so I could consider the exposure of teachers in the use of technology. I could also understand the language and terminology that they used in the integration of GeoGebra.

Using different instruments to gather data on the same issue permitted me to assess the authenticity and accuracy of the collected evidence. For example, through observation, I was able to crosscheck the information that the participants shared during the interviews. I was also able to validate the information that I observed with information from the policy framework and the GeoGebra manual. This method of crosschecking helped to reduce bias and subjectivity, consequently increasing the dependability of the findings of the case study.

### 3.8.2 Member checking

Member or participant checking involves obtaining feedback about the data from the participants (Anney, 2014). I did member checking in the study by giving the transcribed data to the participants in order for them to check the credibility of the data, that is, that the collected information was accurate. Creswell (2013) warns that it is not sufficient to give participants raw data to check for accuracy. Hence, I also held follow-up meetings to establish whether they agree with the collected data. I addressed the queries and misrepresentations with the various participants to ensure the accuracy of the collected data.

### 3.8.3 Prolonged engagement in the field

Prolonged engagement of the researcher in the field improves the trust of the participants and provides a greater understanding of participants' perspectives and understanding (Onwuegbuzie & Leech, 2007). It is recommended that a researcher stays in the field long enough to ensure that the data collected are credible. I spent eight weeks at the selected high schools in the Bojanala district. I had at least three interviews with each participating teacher to gain their stories on how they integrated the GeoGebra software in their mathematics teaching. I spent one to two weeks at each school for class observation. In some instances, I followed up with teachers with telephone conversations. This continuous contact with the participating teachers ensured continuous contact with the site for clarification of the information and observation to the point where there was no additional information to be gleaned.

## 3.9 Ethical consideration

The research process is known to create some level of tension between the objective of the study and the personal rights of the selected participants to maintain inconspicuousness. For that reason, ethical issues in research are concerned about the code of conduct and maintenance of what is good or bad in conducting research (Babbie, 2010). The privacy of the participating teachers in this study was maintained by concealing their names and using pseudonyms instead.

Ethical issues relevant to this study included ethical clearance by the University of Free State. I obtained an ethical clearance certificate (***Appendix C***) from the University of the Free State, as guided by the ethics guidelines of the university. I further requested permission to conduct research from the North-West DoE and the schools where the four selected participants taught. The selected participants were given letters of informed consent that explained the study and their role in it (cf. Sanjari et al., 2014).

Qualitative researchers also need to ensure that their selected participants are legally and psychologically qualified to give consent and are aware of their freedom to withdraw at any time. As part of the issue of ethical clearance, a letter was received from the DBE in North-West granting permission to conduct research at three high schools in the Bojanala district (***Appendix D***). I also wrote letters to the principals of the selected schools for permission to conduct research at their schools (***Appendix***

***E***). Consent letters were also written to the four selected teachers, requesting them to be participants in the study (***Appendix F***). The letters written to the teachers gave a detailed explanation of the study and the expectations for them as participants in order for them to have a clear understanding of their participation in the study. The participants were informed of their voluntary involvement in the study. I explained that their involvement in the study was voluntary and that their identity would be kept confidential (cf. Pollock, 2012). A detailed explanation of their role in the study was provided. I assured them that their anonymity would be preserved and that their personal names and the names of their schools would not be mentioned anywhere in the research study.

## 3.10 Summary

This chapter captured the discussions pertaining to the research methodology followed in the research in order to gain an in-depth understanding of how teachers integrate GeoGebra in the teaching of mathematics in high schools located in the North-West Province. The qualitative research design and the preferred data collection techniques were also discussed in detail. The discussion elaborated on how the collected data were analysed through the process of coding, categorising and, finally, interpretation. The various measures that were considered to ensure ethical clearance, reliability and the trustworthiness of the collected data were explained.

Chapter 4 discusses the analysis and interpretation of the collected data.

# Chapter 4: Data presentation, analysis and interpretation of findings

## 4.1 Introduction

This chapter presents the results of the collected data and discusses the data analysis and findings of the study that emerged from exploring teachers' understanding of and views on how they integrate GeoGebra software in their teaching of mathematics in South African high schools. The analysis and findings were derived from the analysis of documents, the narratives of the experiences of the four teachers who participated and my non-participatory observation of their teaching sessions. For a clearer presentation of the data analysis, the chapter is divided into two sections.

In Section A of the chapter, I provide the documentary evidence. The document analysis enabled me to provide evidence of CK that is within the South African high school curriculum, the policy that informs the proficiency and understanding of ICT hardware and software, as well as the PD of teachers in the integration of GeoGebra in the teaching of mathematics. Hence, the documents that pertain to the integration of GeoGebra and ICT and the teachers' lesson plans were studied as part of the data collection to understand the information and PD available to teachers in the integration of GeoGebra.

In Section B of this chapter, I provide the detailed narratives of the four purposively selected teachers drawn from three different South African high schools. The presented data were collected through semi-structured interviews with the selected teachers. For each participant, I then present the data that were obtained from non-participatory lesson observation, including when and how they integrated GeoGebra in their mathematics classrooms.

## 4.2 Summary of emerging themes

The emerging themes and their link to the sub-research questions are summarised in the table below.

**Table 4.1: Summary of emerging themes**

| Sub-research question | Background of the emerging themes | Themes |
|---|---|---|
| What are teachers' perceptions of the integration of GeoGebra in the teaching of mathematics in South African high schools? | The formulated themes express the background of the selected teachers in terms of the following:<br>• Their qualifications and experience of teaching mathematics<br>• An expression of the teachers' ability and skills in the integration of GeoGebra in terms of their CK and PCK<br>• An expression of the teachers' ability and skills in the integration of GeoGebra in terms of ICT and ICT software skills | • Background<br>• CK and PCK<br>• Integration of GeoGebra and its connection to the South African curriculum<br>• Perception of teachers on GeoGebra software in the teaching of mathematics<br>• Teachers' challenges in the integration of GeoGebra in the teaching of mathematics |
| What are teachers' practices in the integration of GeoGebra in the teaching of mathematics in South African high schools? | An expression of how teachers integrate GeoGebra in terms of the content of the CAPS document and their actual practices in the integration of GeoGebra | • Mathematics CK and PCK<br>• Integration of ICT in the teaching of mathematics<br>• Integration of ICT software in the |

| Sub-research question | Background of the emerging themes | Themes |
|---|---|---|
| | | teaching of mathematics<br>• Teachers' practices in the teaching of mathematics using GeoGebra<br>• Instructional practices/strategies |
| What kind of PD support (if any) is provided to teachers in the teaching of mathematics using the GeoGebra software in South Africa? | An expression of the training and support awarded to teachers for the integration of GeoGebra and other related ICT and software support | PD support |

## Section A

## 4.3 Results from document analysis

Bowen (2009) refers to document analysis as an organised system for reviewing and gauging documents and electronic material with an aim to derive meaning and gain an in-depth understanding of the information obtained from interviews and observations. The analytical process involves the reading of obtained documents with a thorough examination of the content, thereby interpreting it and deriving meaning from it.

Taking into account the main objective of the study, which is to explore how teachers integrate the GeoGebra software in their teaching of mathematics, it becomes apparent that the integration of GeoGebra as mathematics software requires aptitude in mathematics as a subject as well as the knowledge of using the various technological tools that are necessary in teaching with GeoGebra. Therefore, in my analysis of documents, I used the *GeoGebra Software Manual*, the national and provincial ICT policy documents, ICT integration framework documents and the lesson plan document that the teachers employed in preparing and presenting their lessons. The documents were selected to provide knowledge and detail of the ICT and GeoGebra software information that the teachers were exposed to as part of their preparation for the integration of GeoGebra. The documents were analysed as a means of gaining an idea of the PD that the teachers had received as part of their preparation for the integration of GeoGebra. The table below elucidates the documents and analysed data from the selected documents.

**Table 4.2: Documents and analysed data**

| **Selected document title** | **Analysed data** |
|---|---|
| Selected teachers' lesson plans | • An understanding of the prepared content<br>• Correct usage of mathematics terms<br>• Planned assessment |
| *Guidelines for Teacher Training and Professional Development in ICT* (DBE, 2007) | • e-Education and CAPS implementation<br>• Teacher ICT knowledge, skills, values and attitudes<br>• Development levels |
| *Guidelines for Schools: ICT Hardware Specifications* (DBE, 2012) | ICT requirements and recommendations for ICT in schools |

| Selected document title | Analysed data |
| --- | --- |
| *White Paper on e-Education* (DBE, 2004), relating to the transformation of teaching and learning through ICT | The use of technological tools in education, and linkage to policy and strategic objectives of education, their funding and implementation |
| *GeoGebra Software Manual* | • The mathematics content that could be taught using GeoGebra<br>• Guidance on how to use GeoGebra to communicate mathematics ideas |

### 4.3.1 Lesson plan

Preparation is an essential part of teaching, where a teacher thinks about the content to be delivered and how he or she will deliver it and have expectations of any possible questions or eventualities that may occur during the lesson. Lesch (2018) says that teachers need to carefully plan the lesson and material they are going to use as a means of being prepared to teach. It is not necessary to deliver the lesson only verbally; actions and activities also form part of lesson delivery. GeoGebra is known to help in lessons and activities, also in the South African high school curriculum (Mushipe & Ogbonnaya, 2019).

As part of data collection, I asked the teachers to share their lesson plans, as I was interested in how they planned to incorporate GeoGebra into their mathematics lessons. Their lesson plans would also provide snapshots of their mathematics CK in terms of their use of mathematics terminology and planned assessment during the lesson. The teachers indicated that the DoE provided them with lists of lesson plan documents titled *Teacher Toolkit: CAPS Planner and Tracker*. The *Teacher Toolkit* documents aim to support the teacher to keep pace with the time requirement and content coverage of CAPS. The *Teacher Toolkit* also provides guidelines for assessment relevant to the covered content. I went through the *Teacher Toolkit* document and found that it was very similar to the CAPS document (DBE, 2011). It appeared to be a summary of the CAPS document. The assessment exercises provided in the document can also be found in the prescribed textbook. The document lacks information relating to the integration of technology for any of the mathematics topics. The national policy on education for mathematics provides guidelines for preparing lessons in mathematics. Furthermore, it provides guidelines on how ICT software such as GeoGebra could be integrated into lessons.

### 4.3.2 Guidelines for Teacher Training and Professional Development in ICT

PD for teachers in integrating GeoGebra and any other ICT tools is essential to equip them with skills and knowledge on how to incorporate technology into the teaching and learning environment. Inadequate PD has been flagged as a reason for the delay in the integration of technology in schools (Konstantinos et al., 2013). In South Africa, there is a circulating *Professional Development Framework for Digital Learning* (DoE, 2018) document which is targeted at building teachers' competencies in facilitating learning with digital tools and resources. The framework is in line with the *DBE Action Plan to 2019* (DBE, 2015) and the *Integrated Strategic Planning Framework for Teacher Education and Development in South Africa 2011-2025* (ISPFTED) (DoE and Department of Higher Education and Training, 2011), which support and are committed to the integration of digital technology in the delivery of the curriculum in South African schools.

The *DBE Action Plan to 2019* (DBE, 2015) recognises the need to supply schools with the necessary technological infrastructure, develop guidelines for school management support and guidelines for teachers on how to integrate technology and provide hardware and software specifically for the integration ICT into the school curriculum. The participants in my study were all familiar with various technological tools and used laptops that had been supplied by the DoE. Even though the schools had spaces for computer laboratories, there were, however, no computers at the schools for the learners to use.

The ISPFTED (DoE and Department of Higher Education and Training, 2011) makes specific reference to the requirement for teacher awareness and pedagogical skills that are crucial to improvement in education and the need to establish professional learning communities to strengthen the teaching profession. Hence, the guide for teacher training and professional training framework was essential in my study to gain a perspective on teacher training in ICT integration. The framework identifies the TK, skills, attitudes and values that are necessary for teachers to implement the curriculum effectively with the support of technology. The framework also recognises the need for teachers to be familiar with a variety of technological tools that are relevant to their subject and also to know when and how to use them. In addition, teachers need to collaborate with other teachers to strengthen their skills (Hindle, 2007). The framework further stipulates the following principles for ICT in teacher development:

- Teacher development programmes should provide teachers with situated or contextualised learning experiences.
- Ongoing support should be consistently available. This includes pedagogic support (from subject advisers in particular), technical support and creating communities of practice.
- Teacher development should be ongoing, due to the changing nature of ICT. Programmes should reflect new technologies and applications.

The participants in this research indicated that there was very limited teacher training that was focused on the integration of ICT software. In instances where teachers received limited training in using ICT software, such as GeoGebra, follow-up was provided by the DoE to strengthen their pedagogical technological knowledge.

#### 4.3.3 White Paper on e-Education

The *White Paper on e-Education* (DoE, 2004) intends to guide the approach of the DoE to integrate ICT into teaching and learning. It stipulates that ICT tools should be used as a set of flexible instruments for teaching and learning and be integrated in the PD of teachers. That means it is necessary to develop ICT skills and knowledge to enhance teachers' teaching environment. Accompanying support should also be provided to teachers in the integration of technology.

#### 4.3.4 GeoGebra Software Manual

Teachers who were introduced to the availability of GeoGebra as a teaching resource were given the *GeoGebra Software Manual* (GeoGebra, 2017). The manual offers the link to download the GeoGebra software onto any computer. The manual encapsulates the use of GeoGebra in teaching and learning mathematics. It provides tools on the use of GeoGebra to teach different mathematics concepts. During the interviews, the teachers indicated that they were aware of the manual.

The manual illustrates how to operate the GeoGebra geometry tool and how to open and save files. It also explains how to draw various mathematical drawings, including triangles, regular hexagons and the circumcircle of a triangle. It further illustrates how to input algebraic expressions and functions and export the drawn pictures to the clipboard. Illustrations of doing the transformation of images or objects on the Cartesian plane are also provided.

## Section B

## 4.4 Case 1: Mr Magwe

### 4.4.1 Interviews – Mr Magwe

#### 4.4.1.1 Background

Mr Magwe has been teaching mathematics and science for the past six years. He has a BSc degree in Computer Science and Electronics as well as a Postgraduate Diploma in Education (PGCE). His experience includes teaching mathematics and physical science and technology at a high school in the North-West Province. He has also been a lecturer at a college where he taught IT. Mr Magwe taught mathematics to Grades 8, 10, 11 and 12. He taught at a high school in the North-West Province and a college at the higher education level prior to working at his current school, where he has been teaching for three years. Mr Magwe's experience is broad, considering that he has worked in a variety of high schools and colleges and has taught mathematics, science and IT. I asked him about his qualifications and teaching experience and he explained as follows:

> *Yeah, basically, so I have been teaching from 2013. I started in a high school here in North-West Province. I was teaching mathematics, natural science and technology. I later moved to Lethabo College, where I was teaching IT. In my school, I teach maths in Grade 8, 10, 11, 12 and teach technology in Grade 8.*

It is evident that Mr Magwe boasts a wealth of experience in the teaching of mathematics and technology and this has positively shaped his teaching profession in mathematics and technology. He has a diverse background in teaching at a college and various high schools in South Africa.

When asked about his experience in mathematics teaching at his current school, he indicated that teaching mathematics was challenging at his school. He pointed out that the presence of the mines and the behaviour of mineworkers affected the learners' actions and, consequently, mathematics learning. According to Mr Magwe, the mineworkers' style of life, especially the exorbitant spending after earning their salaries, influences the learners negatively and distracts them from learning.

> *Ok, uhm … it's challenging … Having the mines around is quite a challenge because we are having different cultures, people from different places. These men from [the] mines … you know … they give learners money and buy them things.*

He further mentioned the impact of the proximity of the mines to the school. Mr Magwe held the view that there was an increase in teenage pregnancy and learner absenteeism as a result of the mineworkers.

> *So … it's hard to get [the] learners to be at school and concentrate in school because they are, maybe, pregnant from these men or they want money to buy nice things … I don't know. Girls … they fall pregnant because they are actually trying to get some money and provide for the family. So, it's quite challenging because just keeping learners in school yards is a challenge [in] itself. Some learners don't come to class after break and go with these men from the mine.*

It was evident that Mr Magwe was dissatisfied with the distraction that was brought about by the mine workers and causing the learners to lose their focus on learning. From the above quotation, it is also evident that female learners were falling pregnant as a means of earning a living for their families. Coupled with all these challenges, learners abscond from school regularly. The South African news has reported on a vast scourge of pregnancy in North-West where young girls are impregnated by older men (SABC, 2019). This recent media coverage on pregnancy is in line with Mr Magwe's concern about high teenage pregnancy at his school, which has an impact on the teaching and learning of mathematics.

Mr Magwe further indicated that learners' lack of concentration and absenteeism would affect the learning of mathematics because continuity is crucial in mathematics. The other reason is that mathematics topics tend to be interconnected.

> *You know … for a subject like maths, Ma'am, learners have to be in class. You can't come to class today and then tomorrow you don't come. In maths, topics connect to each other.*

Follow-up was done to establish how Mr Magwe felt about teaching mathematics at his school. He mentioned that learners as young as Grade 10 were playing parental roles at home, taking care of their younger siblings and losing time to focus on their school work. A lack of parental support will affect performance in a subject such as mathematics, which requires constant practice.

> *Yuh! Ma'am, at this school, it's hard to get learners to concentrate in school because some of the learners are household-headed or you find that the learner is in Grade 10 but he's the eldest at home. You know … a subject like maths, you need to practise and practise it. Learners don't have time for school work. You know ... a subject like maths, learners think is difficult, so if they have to be parents at home … we have a problem, Ma'am. They won't have time for maths.*

The evidence above shows that Mr Magwe was concerned that learners were missing opportunities of learning because they were overwhelmed with the responsibility of being parents themselves to their younger siblings. Okafor et al. (2013) concur that the family environment has an effect on the performance of learners. Hence, Mr Magwe's view on the impact of the lack of parental support for these learners is justified.

Follow-up was done to establish whether more challenges affected the performance of learners in mathematics. Mr Magwe indicated that the learners generally did not do their homework at school. As a result, he avoids giving learners homework and gives them classwork instead. He believes that the lack of homework is not suitable for learners because they still need to go through what they have learnt in class independently.

> *Uhm … you know, Ma'am, most of the time, you end up avoiding homework because they don't write it, [the] majority of them. So, you end up giving them classwork. But some of them will do it. But what is the point if most learners did not do the homework. In maths, you have to try and do the problems alone. Ah, these learners don't do homework. You give them today and tomorrow you ask for [the] homework. You find [that] no one did it, or maybe one or two learners.*

It was evident that there were challenges with learner assessment because of the issues relating to homework as another form of assessment. Most research studies indicate that homework is an essential part of learning as a way of assessing if learning has taken place. Gustafsson (2013) affirms that homework helps with ensuring the repetition of the work done in class and, consequently, encourages learning.

Mr Magwe continued talking about the challenges he faced in teaching mathematics at his school. He felt that the school had limited resources for the learners, especially in technology.

> *Hey … that is our biggest challenge and then you know, technology … this is regarded as a rural school; we don't have much technology equipment, especially for learners. And then, most of the learners, we have noticed that they learn more on observing, when they see things, that's when they get interested. So, if you just keep on talking, they eventually lose interest. So, if learners had computers, they would use it to experiment; maybe watch videos and revise what they didn't understand in class.*

According to Mr Magwe, mathematics is abstract for most learners and technology is useful for conceptualising mathematics ideas.

> *Mathematics is abstract for most learners. You can tell when teaching that they are lost. They will tell you, "Where will I use this maths?"*

With all the challenges indicated by Mr Magwe that had an impact on the mathematics learning at his school, I asked him about the mathematics performance of the learners at his school in the various grades, considering all these circumstances. He indicated that mathematics performance was poor in Grade 8 to 10, but they noticed an improvement in Grades 11 and 12. He attributed the lower performance to overcrowding in the lower grades. On quizzing Mr Magwe on other challenges in teaching and learning mathematics with technology, he mentioned that the classes were smaller in Grades 11 and 12 and the learners were more focused in those grades.

> *Hmm … in the lower grades, I can say classes are bigger there. It is difficult with those learners. You find that Grade 8 learners come from primary school very weak in maths. They don't know the basics but by the time they get to Grade 11 and 12, those are serious learners. We got [a] 100% pass in matric last year [2018] in maths and science.*

A follow-up question was posed to establish to what he attributed the improved mathematics performance in Grades 11 and 12 and what the school was doing to assist learners in Grade 8 to 10. Mr Magwe indicated that they changed teachers to allocate their best teachers to the worst-performing grades.

> *I would say, for the past years, we have moved our strong teachers to teach the lower grades [Grade 8 to 10]. This helps because when these learners come to Grade 11, they are sure about their stuff. That's why our Grade 11 and 12 perform better.*

The evidence above shows that the school has taken an initiative in addressing the poor performance in mathematics that Mr Magwe has mentioned. His comprehensive experience in teaching mathematics at different high schools and colleges is ideal for this study because he has worked with a variety of learners. He was able to note various factors, including teenage pregnancy, inadequate family support, a lack of homework for assessment and limited ICT tools for learners, that were affecting the teaching of mathematics at his school.

#### 4.4.1.2 Mathematics CK and pedagogical knowledge

When there is an integration of mathematics software in the teaching of mathematics, it is essential to establish the mathematics CK of teachers. Koehler et al. (2013) refer to the CK in this context as the teachers' level of understanding of mathematics and how it relates to real-life situations and the ability to use the correct mathematics terminology. Hence Mr Magwe was asked to narrate how he taught various mathematics topics in the South African curriculum. He first made an example of how he introduced mathematics lessons by first quizzing learners about what they understood about, for example, trigonometry and statistics. In his examples of trigonometry, he said:

> *Uhm, most of them, before I start a topic, I ask them why, for instance, do we do trigonometry. They don't have any idea; they assume we just do it for passing and moving to the next grade. They cannot relate what you are doing now with the real-life situation, with the course related to it.*

He continued by giving examples of how he introduced mathematics topics by talking about how he helped learners to relate statistics concepts to real life. He referred to examples of categories in a statistics topic.

> *So, yeah, then eventually, that is what I do first, then say: "Okay, you are doing statistics, where can you work with statistics? What is your job category? For example, job category could be education if you are a teacher and maybe health if your job is a doctor."*

He proceeded with the statistics example and mentioned the role of Statistics South Africa (Stats SA) when they collect data about the number of black or white people, or the amount or percentage of unemployed people in South Africa.

> *And that is where I would say: "You usually see people coming to your houses, counting you and so on, that's Stats SA. Stats SA will tell you, South Africa has so many black people and so many white people. They*

*will tell you so many people are not working in South Africa. Yah … they use stats to tell you that information."*

Mr Magwe emphasised the statistics example and mentioned that he would even bring the statistics example to the learners' school environment through the statistics chart that hung in his school staff room. This statistics chart is used to group the learners at the school into various categories.

> *I will tell them: "And when you go to the staff room, you will see there is a chart that states that we have 300 and so on learners … that is statistics. It will tell you, you have so many girl or boy learners, how many learners are in Grade 9 … whatever grade."*

The quotations above show that Mr Magwe connected the statistics concept to various aspects of reality that learners are familiar with.

Mr Magwe was keen to give another example relating to the application and understanding of statistics. He gave another example that related to the lifestyle data questionnaires that shop assistants at shopping malls would generally give to passing shoppers. The questions could be referring to a particular product or some shopping tendencies that the learners could observe when they went shopping.

> *So, usually I tell them that when you are in Brits Mall or so on you see people asking: "How many times do you go to the gym and so on." So, they are trying to get the statistics. Or, they could be asking about your favourite brand of shoes or something. Yah, they could be asking how many time you go to Checkers.*
>
> *You can basically work anywhere as long as you are dealing with collecting data. Analysing it then afterwards, you make a conclusion based on it, and that's where now they start: "Okay, oh, alright."*

It was clear that Mr Magwe understood the application of statistics, but interesting to note, his examples lacked the use of mathematical terms, even when probed to demonstrate the correct usage of mathematical terms. He expressed the accurate understanding of the sequence of data collection and that it is meaningful when analysing it.

He gave an example referring to the calculation of a cylindric object. In order to help the learners understand, he would bring to class the core of a toilet paper roll and show them that it has two circles on the two opposite ends. Then he would cut the toilet paper core across and show the learners that it becomes a rectangle. Hence, the calculation of the cylinder object includes the area of the two circles and a rectangle. Erduran and Ince (2018) maintain that the presence of CK is established when the teacher uses mathematics terms correctly, is able to relate the mathematics concepts and able to address the critical concepts. In this instance, Mr Magwe demonstrated his understanding of the content when he used the correct mathematics terms in referring to the three-dimensional shapes, the calculation of the area and linking the spherical shape to various practical cylinder shapes. He mentioned how the formula of the area of the cylinder is determined. He further gave the detail that the formula of the cylindric shape emanates from the sum of the two circles plus the area of the rectangle.

> *Let's say I am teaching 3D shapes. Learners find this difficult to understand. So, let's say we calculate the area of the spherical shape. I could take any shape, say, this spray [pointing at the air freshener spray that was in front of us]. You see, it has two circles and then the rectangle. Or the great example is the core of the toilet paper, you know, that brown part when the toilet paper is finished. I take that to class and I show them the circles and then cut it once across. Then they see circles and then the rectangle. We will then physically calculate the area. From this, they also understand where the formula of the area of the sphere comes from.*

From the conversation with Mr Magwe, there were indications that he had a good understanding of mathematics content, especially when referring to geometric concepts. He further presented good pedagogical skills from his examples, demonstrating his understanding of how mathematics concepts linked with real-life situations.

#### 4.4.1.3 Integration of ICT in the teaching of mathematics

There is an urgent need to equip South African schools with various forms of technology. Hence, the DBE (2012) has provided guidelines to schools for ICT hardware and software. The document states multiple hardware and software tools that each school in South Africa should have. I, therefore, sought to establish from Mr Magwe the ICT tools that he was exposed to at his school and how he used them in the teaching and learning of mathematics. He said that the school had laptops for the teachers and tablets for learners and teachers.

> *In our school, Ma'am, we were lucky that we received so much donations. I have a laptop that I use. Some laptops were donated for teachers. There were also tablets that were donated for learners and for teachers.*

Mr Magwe continued by counting the other ICT tools they had at his school. He mentioned that the school had one projector that was shared among all of the teachers. The school also had an interactive whiteboard that was located in their computer laboratory.

> *We have one projector that we exchange with other teachers. It is a projector for the whole school. If the economics teacher needs it … he uses it. Physics teacher needs it … he uses it. We used to have [an] interactive whiteboard that was in the lab. Yooo … learners enjoyed working on it.*

It was evident that the school had a wide variety of technological tools at its disposal. It was also established that the learners were exposed to using tablets in their learning of various school subjects. Mr Magwe further indicated that the tablets were preloaded with mathematics content and question papers to use for revision.

> *The tablets were good because they had some maths content … question papers and memorandum. The other good thing was that there was wi-fi on those tablets.*

Follow-up was done to establish what had happened to the many ICT tools that the school had had, as Mr Magwe kept referring to them in the past tense. He explained that the school used to have a computer laboratory that had about 20 computers. However, there was a burglary, where all the computers and tablets had been stolen.

> *Ah! Honestly speaking, it was a painful experience when we came to school one day. All the gadgets from the storeroom were stolen. The computers were stolen from the lab. The interactive board was taken from the wall. It was bad … I think it's people who knew where we keep our technology. After that, [the] learners did not have any computers.*

Mr Magwe spoke with a very heavy heart, explaining that the loss of these technological tools had left a big void at the school. He indicated that it was a huge loss for the school, especially because not all of the ICT tools that had been stolen were replaced. Mr Magwe indicated that since the incident, the school had made it compulsory for learners in Grade 12 to own smartphones. Watson (2015) affirms that there are benefits to using cellular phones as part of teaching and learning.

> *In Grade 12, we call [a] parents' meeting to ask parents to buy learners cell phones. Even cheap cell phones for R500, as long as it is a smartphone. If you try and say learners should bring their cell phones. Yes, it's against the school policy because some learners now will start doing other things instead of being in [sic] the lesson.*

ICT has become an integral part of teaching and learning and is used for various purposes; hence it was imperative to establish how the teachers integrated the ICT tools at their disposal in teaching mathematics. I therefore asked Mr Magwe which activities he conducted using the ICT tools at his disposal. Mr Magwe explained that he sometimes made learners watch mathematics videos where the various three-dimensional shapes were demonstrated. As an example, he stated that it was often difficult to explain a cone shape to learners, especially when they had to calculate the area and volume of the cone. He would then find a video that showed the cone in different directions and took the actual cone object apart. On the video, the learners were able to see the circular and triangular parts of the cone. A drawing of the cone on paper or the board does not show these aspects at all; so learners have to use their own imagination in understanding the various properties of the discussed object.

> *Let's take the 3D shapes, for example. I like showing learners how these items look like in real life. I would look for good videos and get one that represents what I want to teach very well. For example, let's say I teach them how to calculate the area or volume of the cone-shaped object. The videos will be turning the object in different directions. They will see the faces. The video will show the differents part of [the] cone, like where we get the circle and where we get the triangle calculation.*

It was clear that Mr Magwe was fascinated by this aspect of technology and sought to help the learners conceptually understand what they were learning by using mathematics videos.

From the above conversation, I could notice the passion that Mr Magwe had towards technology. I probed further to establish how he used the interactive board in the teaching of mathematics. He explained that he used it for peer learning, where a learner would be allowed to teach a mathematics concept that they had learnt in class. The learner would then use the interactive board to educate, and the learners would be fascinated by the reaction from touching the board. The videos would then be circulated on WhatsApp and the learners could watch and share these with their friends and family.

> *You know … learners loved the interactive board. It was at the lab. When I said we were going to the computer centre, [the] learners will be excited because they knew we were going to record the videos. I would make them teach something that we did in class. I record them teaching. The video will then be posted, say on WhatsApp. They like seeing themselves*

*on the video. They will show their friends and family videos when they were teaching in class.*

It was fascinating to note that this strategy allowed learning to continue even after class. Mr Magwe was creative in bringing technology into his classroom and ensuring that the learners were interested in learning.

Mr Magwe elaborated on the other ICT tools that he used to enhance his teaching experience. He mentioned that he used the projector for the learners to watch videos, demonstrate GeoGebra and show the learners prepared mathematics content on his laptop.

*The projector? I use it in class … Sometimes I have YouTube videos or some of the mathematics software or question papers that were donated. I just plug [in] the project and they watch the videos. Sometimes, say I'm using GeoGebra … I can project GeoGebra on the whiteboard. Maybe sometimes, I have prepared some work on the laptop and then I can show the learners.*

It was evident that Mr Magwe had good exposure to technological tools and used the projector for various mathematics activities in his teaching.

In a conversation, Mr Magwe went into greater depth in explaining that having a projector was a major breakthrough because he could download videos and the learners could watch them in class using the projector.

*You know, Ma'am, the projector has changed learning in class. At least now I can download videos or use videos that were donated to the schools and [the] learners can watch these videos.*

Mr Magwe explained that some mathematics concepts were difficult to illustrate on the board. For example, he mentioned that the formula for the area of the cube is six times sides square ($Surface\ Area\ of\ Square = 6a^2$). The drawing of the square shows three faces for learners to be able to understand how the formula of the square comes about. Mr Magwe said that he would bring a video to class where the cube would be illustrated showing all the faces. This integration of ICT tools helps with the visualisation and enhances the understanding of mathematics concepts.

*It is very difficult to draw a 3D diagram. For example, when we talk about the tetra, you draw it and it does not come out the way it is supposed to. You look for a video that shows the cube where they are turning it. Then you can show learners that you talk about three-dimensional and we say we have an area this way and this way. When you spin the diagram, you*

> *see all sides. Then you explain to the learners that that's why when we calculate the area, we have this formula.*

It was evident that Mr Magwe used various kinds of ICT tools to communicate mathematics ideas in class.

Since Mr Magwe had mentioned earlier that he also used the tablet as an ICT tool in his teaching environment, it was interesting to learn how he used the tablet in his teaching environment. He explained that he used the tablet to save his lesson plans and referred to it during teaching time. He also used the tablet to store his class analysis, where he recorded the learners' performance. Mr Magwe also used the tablet for administration purposes, where he recorded whether learners have submitted their assignments or homework.

> *Okay, what we'll do is that, usually my lesson plans and everything, I would set them on the tablet. So, for the lesson plan, I keep it on the tablet and it helps me to maybe conduct data, maybe some learners who didn't do their homework; it's easy for me to record their names there.*

It was clear that Mr Magwe was keen on using his various technological tools to engage with the learners and for administrative purposes relating to effective learning.

Follow-up was done to understand how the integration of these ICT tools influences his teaching strategies. Mr Magwe mentioned that he preferred a strategy where learners discovered their own learning. Therefore, he engaged the learners instead of doing all the talking himself and the learners just listening.

> *Teaching strategy? Hmm … Learners are happy when I bring any ICT tool. They will be like: "Sir, Sir, what are going to do today?" I let them try as well. I also ask them questions so they think about what we are learning.*

There was a need to establish how the learners engaged with Mr Magwe as a teacher in their learning, especially with the use of cellular phones, as he had previously mentioned that the Grade 12 learners needed to own cellular phones and they used their phones for the WhatsApp group that they had formed. Sometimes a learner might struggle with solving a mathematics problem and pose a question on the group. Other learners would attempt to solve the problem and post it on the group or he would respond to the question himself.

*We use WhatsApp a lot for maths. Let's say learners are working on a question paper. They get stuck when solving a problem, neh? Then they post a problem on a group or ask something. Other learners respond. Sometimes they are wrong or something. I then answer or take a picture and give them the solution.*

From the quotation above, it is clear that the cellular phones provided a good platform for peer learning and continued learning interaction with the teacher. The teacher was making use of this. He was also orientating the learners not to simply post answers but to assist one another to arrive at solutions; this process constructed their individual knowledge with one another's assistance.

Despite various literature works showing resistance among teachers to use ICT tools in their teaching (cf. Van Wyk 2014), Mr Magwe challenges this notion of resisting technology. He is one of those teachers who embraces the integration of technology in the teaching of mathematics despite the challenges that exist at his school. Once more, we see a wide spectrum of practice in terms of how teachers integrate technology into their mathematics teaching in high school.

#### 4.4.1.4 Integration of ICT software in the teaching of mathematics

There was also an interest to establish the practice in the integration of various software tools that Mr Magwe was exposed to. The Department of Education makes reference to the specific minimum software tools that are needed in a learning environment, which include word processors, spread sheets and presentation software. Mr Magwe indicated that he used a variety of software tools for different purposes. He was aware that there was a wide variety of mathematics software. Besides using GeoGebra, he used Microsoft Word and Microsoft Excel.

*Let me see … software? I use GeoGebra but, yes, Microsoft is the common one. I use Word. I also use Excel. It is very good to use when you want to draw graphs and you don't want to use GeoGebra.*

This study makes a distinction between hardware and software tools. Even though the study is focused on the GeoGebra software, it is also essential to consider other software tools available in the teaching and learning environment. Most of the software are interrelated, and there was an interest to know how Mr Magwe used the software tools that he was exposed to. He mentioned that he used Microsoft Excel for statistical calculations and drawing graphs.

*Yuh … I use Excel a lot. For example, when you have statistics data, neh. You can get like an average, mode or frequency of data. It is also nice, like when you want to draw a graph, say you want to do pie charts or any graph. It's good.*

Mr Magwe continued to explain how he used Microsoft in the teaching of mathematics. He indicated that he also preferred using it when setting question papers. For example, he enjoyed using the Microsoft Excel feature that when one copies the graph or captured data from Excel to Microsoft Word, one can click on the data in the Microsoft Word document and it will lead the user to the same data or graph on Excel.

*Mostly I use Microsoft because it is the common one. I use Excel because it can plot graphs when it is linked to Word. For example, when I set question papers … When you want to generate graphs, you just link it to Excel and it transfers it to Word automatically.*

Mr Magwe had mentioned earlier that he also enjoyed using Microsoft Word; therefore, I sought to establish how he used it in the teaching of mathematics. He said that Microsoft Word was good for typing question papers and setting assignment questions. He thought it was easy to copy and paste various mathematics figures into Microsoft Word.

*I use Word a lot for typing assessment. Like … I would type the exam or test or maybe assignment. You just copy and paste a diagram on Word … it's easy. You just type on Word and make copies and then learners write a test. Imagine if you were to write on the board! Sometimes, the handwriting is not clear. And it takes time to write on the board.*

Mr Magwe, however, expressed a challenge with regard to Microsoft programs. When it came to drawing angles using Microsoft, he felt that it was difficult to draw the exact angle sizes but he retorted that they were other software programs that he had grown to appreciate, including GeoGebra, that were more accurate in illustrating various angle sizes.

*I have once tried … Microsoft. But it always limits you; the triangles wouldn't be that perfect, sometimes, because they don't give you your 90 degrees angles like GeoGebra. It isn't that it gives you a chance of selecting any angle that you want, but there you just assume the angle. So, I once tried to use Microsoft, but it was not that perfect, yes.*

From the above quotation, it emerged that Mr Magwe had tried to use the Microsoft tools to illustrate some geometry concepts in mathematics. However, he could not achieve the results he wanted because of the limitation within the Microsoft software and consequently explored GeoGebra as an alternative software tool.

#### 4.4.1.5 Integration of GeoGebra and the connection thereof to CAPS

The CAPS document (DBE, 2011) outlines the mathematics content areas that need to be taught in South African high schools. It declares that the mathematics content should be taught in a manner that develops the learners' mathematical reasoning and creative and reasoning skills (DBE, 2011). On the other hand, the study is focused on the teachers' experiences of the integration of GeoGebra in the teaching of mathematics in South African high schools. Hence, it was important to establish from Mr Magwe what he thought of the link between the mathematics curriculum, as according to the CAPS document, and what GeoGebra software could do. Mr Magwe indicated that most topics from the CAPS document could be taught or revised using GeoGebra.

> *Yeah, because [for] most of the topics that are there, you can use GeoGebra. For example, the graphs, trigonometry and geometry are there on the CAPS document and you can also teach them using GeoGebra.*

With regard to the link between the mathematics content as addressed in CAPS and GeoGebra, Mr Magwe added that in preparing the lesson using GeoGebra, he noticed the link between the mathematics topics. The content connection then helped him to emphasise topics that he had already covered in class as part of the revision. Mr Magwe gave an example that he could be talking to learners about lines, but when the lines are connected, they can form an acute angle. He could then also develop the concept further to explain triangles.

> *And then, as we are doing GeoGebra, at some point, it gives you an idea on how to teach it because some things, you don't notice them until you are teaching GeoGebra and you say, "but this is how I can link the topics", like I was saying with lines. Usually we just say "straight line blah-blah", and then we just move to triangles, until you notice that if I draw the one line and join it with the next one, now I can introduce the concept of the angles.*

Mr Magwe further explained how he used GeoGebra to connect with the mathematics content specified in the CAPS document (DBE, 2011). In the above quotation, he explained that he had realised the connection between straight lines and triangles when working with GeoGebra. He then used that new knowledge to enhance his mathematics lesson. Mr Magwe further explained:

> *Then from that, when you add the third line, it creates a triangle. From that you can bring a concept of a triangle. It helps you to start somewhere and move to another stage, and s, it gives you an idea, instead of just going to class and saying "today we are doing triangles". Whereas they cannot relate what you have been doing previously with triangles.*

He further explained that the link between lines and triangles helped the learners clear the confusion of calculating angles and the length of the line.

> *You find that when you say "calculate the angle", instead they will find the length. That's why sometimes our learners are failing. Not that they don't know the concept, but they don't understand the question.*

The CAPS document (DBE, 2011) specifies that the mathematics content in high school should be taught in a manner that prepares learners for abstract mathematics at tertiary level. Hence, teachers should aim to help learners to understand mathematics conceptually. Mr Magwe mentioned from the example of the distinction between calculating the angle and the length that GeoGebra helped to clarify, GeoGebra was able to make the distinction between the angles and length related.

> *So, when you can relate, it stays in their mind that I cannot have an angle that is 180 degrees because it's just a line. When the lines have been connected and triangles drawn, learners see, this is the angle and this is the length. And they see, oh, this is how I calculate this and calculate the length here.*

The CAPS document (DBE, 2011) specifies 10 subject areas that need to be taught in high school mathematics. These have been discussed in detail in Chapter 2. It was thus interesting to gather from Mr Magwe which of the subject areas he enjoyed teaching with GeoGebra. Mr Magwe mentioned that he enjoyed using GeoGebra when teaching geometry, trigonometry and functions, particularly for drawing graphs in algebra.

> *It's geometry and trig. Yeah, even graphs, yeah. Most of the time, like in algebra, we draw two different graphs. For instance, say quadratic graphs and linear graphs.*

The purpose of this study is to explore how teachers integrate GeoGebra in teaching mathematics in South African high schools. As Mr Magwe indicated that he used GeoGebra to teach key mathematics subject areas such as trigonometry, geometry and algebra, I asked him how he used GeoGebra to teach high school mathematics content. Mr Magwe described how he used GeoGebra for teaching trigonometry graphs. He mentioned that he used GeoGebra to explain to learners the amplitude and wavelength points in the trigonometric graphs. Brzezinski (2017) concurs that GeoGebra is vital in teaching trigonometry functions and trigonometry graphs because, in his experiment, learners who have been taught trigonometry by using GeoGebra performed better than learners who have not been exposed to GeoGebra.

> *And then again, maybe talk about aptitudes and so on, maybe we are talking about trig graphs. Then learners would fail to differentiate between the amplitudes and wavelength. Then immediately, it gives you a point where you can measure from one point. You can choose one point and so on. Then they turn to follow it that way.*

In the above example, Mr Magwe described how he taught trigonometric graphs and indicated that his inclusion of GeoGebra helped learners to understand better.

GeoGebra is known to help learners visualise the abstract aspect of mathematics. Therefore, it may be vital for a teacher to use it where particular concepts have been taught and the teacher wants the learners to conceptualise the learnt ideas through revision. GeoGebra is recommended for use in teaching geometry in the new Slovan and Malaysian curricula (Gunčaga et al., 2012). Mr Magwe explained how he used GeoGebra to teach geometric concepts within the South African curriculum.

> *Then, properties of different triangles, what happens when you get another side of the triangle, then what happens to the angle? For example, with GeoGebra, you can draw a triangle, say with [a] right angle, say … a right-angle triangle. Then you explain that this triangle is called a "right-angle triangle". Then I draw different triangles and ask learners to tell me the name of the triangle.*

From the above quotation, it is clear that Mr Magwe uses GeoGebra to examine and explore geometry principles on triangles.

Mr Magwe further explained how he integrated GeoGebra in teaching the functions concept in algebra. Armah et al. (2012) stress the importance of GeoGebra in teaching algebraic equations and graphs, which allow learners to draw graphs and explore various changes in variables. Mr Magwe explained that he enjoyed using GeoGebra often when teaching graphs in algebra, where he drew different graphs, namely linear or quadratic graphs. He would use drawing the graphs as a class activity where the learners would be asked to interpret the graphs or point where the graphs are equal or where the functions are increasing or decreasing.

> *Then we'll ask learners to interpret the graphs, the points where the graphs are equal. Yes, where the function is increasing or decreasing. Yes, we draw, and they interpret the graphs. I will make learners explore changes, say in gradient. They would check what happens to the gradients of two lines if, say, the lines are parallel.*

A follow-up question was asked to establish other practices that Mr Magwe used in teaching GeoGebra in his class. He mentioned that mathematics used unique language at times and information could be lost when learners did not understand the meaning of the word. He referred to the word "shift" when teaching algebraic graphs, stating that learners commonly misunderstood the shifting of the graphs along the x-axis or y-axis.

> *You know, most of the time, learners are confused by the words we use. Like when we talk about the graph "shifting". I will be talking about the shift along the x-axis or maybe y-axis. Learners will be confused. But when I show them what I mean when on GeoGebra software, then they see what I mean.*

It was impressive how Mr Magwe considered the misconceptions in learning of functions. The functions concept is one of the mathematics topics in high school that learners fail to understand the most. He was able to use GeoGebra to clarify such misconceptions. He further explained:

> *Then the learners would basically, maybe you choose one randomly, so and say "can you shift this point up or down, it's your choice", while others are observing what happens to the angles.*

It was evident that Mr Magwe used the learner-centred teaching strategy in the integration of technology because of what he had mentioned about his engagement with the learners.

Most research studies point out various challenges involved in the integration of any technology. It was, therefore important to learn whether Mr Magwe had experienced any challenges when teaching mathematics using GeoGebra. He mentioned that the main challenge was that he had not received training in how he could integrate GeoGebra.

> *You know, Ma'am, I can say GeoGebra is good and is free, but it is difficult because no one showed us properly how to use if for this and for that.*

> *There are [sic] something that I want to do [with] GeoGebra but, yoo, I struggle and just leave it.*

He further explained that another challenge was that learners did not have access to computers; therefore, they could not work in GeoGebra independently. It would benefit the learners if they had computer stations to experiment with GeoGebra.

> *Since they stole the computers, there is no lab or computers at the school. So, learners can't work on GeoGebra. They could play and learn. Maybe do some of the things we did in class.*

Mr Magwe further mentioned that it would certainly be beneficial if the school had more than one projector because sharing the projector made it difficult to use GeoGebra when one wanted to.

> *So, sometimes, say you want to use GeoGebra, but the economics teacher also wants the projector. Then you can't use it. But [f] there was another projector, then you just use it and it's fine.*

From the discussion with Mr Magwe, it was evident that he enjoyed using GeoGebra for teaching mathematics. He also noted the challenges that he experienced in the teaching of mathematics using GeoGebra.

#### 4.4.1.6 Perceptions of teachers on GeoGebra software in the teaching of mathematics

To dig deeper into the purposes of the study, it was interesting to explore Mr Magwe's perception of integrating GeoGebra in the teaching of mathematics in South African high schools. I asked him about the conception of his knowledge of GeoGebra. Mr Magwe mentioned that he had first heard about GeoGebra three years previously at a workshop that had been conducted in Rustenburg.

> *Firstly, when I heard about GeoGebra, we were in a workshop. It was 2016, in Rustenburg. Yeah! It was from a workshop, because most of the subject facilitators at the workshops … they usually use the projectors and laptops. So, that's when … when we were doing the angles and so the facilitator was using it and it was like … okay, that's interesting.*

The first encounter of GeoGebra for Mr Magwe was passive during workshop training that was meant mainly for the integration of ICT. I asked Mr Magwe what his view of GeoGebra software was. He was of the opinion that GeoGebra was beneficial, especially in drawing accurate drawings, and suitable for the visualisation of mathematics concepts.

> *... it's good because we were struggling with the diagrams. Even if we have to set our own test or something, we had to find a certain model from a previous question paper, cut it, then paste it on the question paper. But now, actually, we can create our own diagrams. And because you see some of the maths ideas on GeoGebra, so learners are able to like visualise these maths ideas.*

He referred to GeoGebra as a good tool to use, as it helped with visualisation and helped learners to understand mathematics concepts better.

> *You know … GeoGebra is good. I would advise any new teachers to learn about it. It is also important to use it often because you forget how to do certain things. But it is good … Learners can see so many things.*

Mr Magwe further emphasised that GeoGebra was the kind of ICT tool that encouraged learners to be excited and independently take part in their learning. For example, when the teacher shows them what GeoGebra can do, they will come to school the next day with even more advanced ideas of what GeoGebra can do.

> *Yeah, because like I was saying, you give them that and you'll be surprised the following day what these learners know; sometimes even the maths you haven't done in class.*
>
> *They would come to you and say: "Are you aware that with that software you gave us yesterday …?" That means when they got home, they didn't go anywhere; they just stayed and they were interested in learning more.*

However, Mr Magwe further shared his views on the challenges with regard to integrating GeoGebra in the teaching of mathematics in South African high schools. He mentioned that his biggest problem was insufficient resources to help learners learn how to use GeoGebra. When talking about inadequate resources, Mr Magwe said that there was no opportunity for learners to work with GeoGebra on computers since the computers had been stolen. Therefore, the learners could not explore GeoGebra independently as they would like to do.

> *GeoGebra is wonderful, but, yooh, it's sometimes challenging to use it because sometimes you want learners to practise using GeoGebra but they can't. Computers from the computer lab were stolen. If there were computers, learners would be able to play with GeoGebra and try different things. Yeah, it would be interesting.*

He continued to explain the challenge with GeoGebra relating to the PD in the integration of GeoGebra. Mr Magwe indicated that he had taught himself about

GeoGebra from watching YouTube videos and would have had better skills in using GeoGebra if there had been more guidance and support.

> *I taught myself from YouTube videos how to use a lot of things on GeoGebra. It would be nice if I can ask someone when I am stuck.*

Despite the challenges faced by Mr Magwe in the integration of GeoGebra, he continued to show a positive attitude by looking for help on YouTube, even though that was not ideal.

Mr Magwe also mentioned that another challenge with GeoGebra was the time needed to prepare a lesson, especially because his skills in using GeoGebra were limited.

> *You know … if I am going to use GeoGebra in class, say the next day. I spend a lot of time preparing. I wish it did not take so much time.*

Several studies show that time is always a significant factor whenever there is integration of any form of technology into the classroom. Mr Magwe contrasted the issue of time when he mentioned that GeoGebra also saved time when working with it in class. Time is critical during lesson preparation, but once a lesson has been well prepared, a lot of time was saved in class. He referred to the time-saving factor when he taught graphs because drawing graphs on the board could be a lengthy process.

> *Eh, GeoGebra is wonderful, you sleep late when preparing the lesson. But when it is done, it's nice. Let's say, I'm teaching graphs. Then for that part of the lesson, instead of re-drawing on the board, you just click and open that page, open and explain whatever you want to explain and then move on to another diagram same time; then you explain the same concept just like that. Because previously you had to draw it on the board. If it's a complex model you take plus or minus five minutes drawing it and learners would be making noise or something. But now you just jump from one diagram to the next; it's as easy as that. But once you are used to it, it's very convenient.*

Mr Magwe was impressed with GeoGebra because he saved time in drawing graphs on the board. A critical factor for him was spending more time learning GeoGebra on his own because, with experience, his proficiency in using it was improved.

The process of drawing a graph may be tedious; learners get restless, and class management then becomes an issue. However, once the graphs are drawn using GeoGebra, learning happens swiftly. Mr Magwe was impressed with the GeoGebra feature of drawing multiple graphs on one Cartesian plane. This allowed the teaching of various concepts at one time and allowed learners to observe the link between different mathematics concepts.

> *Now whatever you do, you are looking at them and there is more interaction with [the] learners. For example, you can draw different graphs on a Cartesian plan on GeoGebra. If you draw on the board, tt will take a lot of time and learners will be talking and making noise.*

#### 4.4.1.7 PD support

In South Africa, there is a circulating *Professional Development Framework for Digital Learning* document aimed to build teachers' competencies in facilitating learning with digital tools and resources. There is a need for teachers to develop their pedagogical foundation when integrating technological tools in their classrooms. There was, therefore, a need to establish the kind of PD that was available to Mr Magwe and other teachers in the integration of GeoGebra when teaching mathematics. He was not impressed with the type of training that was provided to them in the integration of GeoGebra. Mr Magwe mentioned that the training happened within an hour. The DoE sent someone from the district, and the official downloaded the software and briefly showed them how the software works for just one hour.

> *The training? It happened so quickly. Just one day we were called at the principal's office. Myself and the other teacher who teaches maths. There was the guy from the Department. I can't remember his name but [he] was from the Department. He told us that there is a mathematics software called GeoGebra and it would help learners with maths. He had the software on a CD and downloaded it to our laptops. The training was quick … maybe an hour.*

A follow-up question was posed to establish exactly what they were shown about GeoGebra. Mr Magwe mentioned that the official from the DoE demonstrated GeoGebra on the laptop and showed them a few things that GeoGebra could do in teaching mathematics.

> *The gentleman had GeoGebra on his laptop and showed us that you open here and then click here. It was interesting. He showed us that you can draw triangles; you can have [a] Cartesian plane.*

From the quotation above, it seems that the training was limited in scope. This was a concern because Mofokeng et al. (2010) claim that teacher training is the key motivational factor for teachers to integrate any form of technology into their teaching. It was, therefore, essential to establish if there was follow-up training from the DoE to check how teachers were coping with GeoGebra. Mr Magwe indicated that it had been two years since GeoGebra was introduced and there had never been any follow-up.

> *Follow-up? The last time we saw the guy from the Department is when he came to show us the software. No one has said anything.*

Mr Magwe further explained:

> *When he [official from the DoE] came, he gave some training manuals in GeoGebra. Those are very good. It is not bad for me because I saw someone talk about GeoGebra before in a different workshop on ICT.*

In our conversation, Mr Magwe indicated that even though he loved to use technology in his classroom when teaching mathematics, there were challenges with regard to effective training. Greer et al. (2016) postulate that the lack of training in the integration of ICT is one of the problems that teachers experience. Mr Magwe also attested to the lack of PD in the integration of ICT as one of the challenges experienced.

> *Eish! I don't want to lie. If there was training, I would be far with GeoGebra. Even though I ask the other teacher who uses GeoGebra. If they can give us like a workshop, then I will do more with GeoGebra.*

Despite the fact that there was minimal support in terms of PD in the integration of GeoGebra in the teaching of mathematics, Mr Magwe indicated that the school had laptops for teachers and had received donations of over 50 computers, tablets and one projector from Vodacom. The school had also received desktops and a mobile interactive board from the local mining company. It was clear that the school had been provided with various forms of ICT tools.

> *In our school, Ma'am, we were lucky that we received so much donations. Vodacom gave us about 50 tablets and we also received more tablets from the other donor, I can't remember the name. But there are over 100 tablets for the whole school. I can even remember because we were discussing that we can now share the tablets with other grades. Because when Vodacom first gave us the tablets, they were only used by Grade 12s.*

With regard to the projector and the interactive whiteboard, Mr Magwe noted:

> *We have one projector that we exchange with other teachers. We used to have [an] interactive whiteboard. The interactive whiteboard was given to us by the mine not far from the school. But it's not like someone showed us how to use this and that. You just use the manual.*

The question remains where teachers get support on how to use such technological tools. I probed Mr Magwe to talk about the time when he had first heard about

GeoGebra, trying to establish whether any form of training and support had been provided to the teachers on the integration of ICT tools in the teaching of mathematics. Mr Magwe mentioned that he had heard about GeoGebra in ICT training about three years previously and further indicated that ICT-related workshops were rare.

> *Firstly, when I heard about GeoGebra, we were in a workshop. It was 2016, in Rustenburg. Then, in 2017, someone came, I think they were working for the Department. He was sent to go to schools to introduce and workshop us on GeoGebra.*
>
> *Yeah, it was from a workshop because most of the subject facilitators at the workshops, they usually use projectors and laptops. So, that's when, when we were doing the angles and so on, the facilitator was using it and then it was like "okay, that is interesting". Then I struggled to follow it, until I was called by the principal that there is someone from the Department to give us the software itself.*

From the quotation above, it was evident that the ICT workshop that had been conducted three years before had been organised for ICT tools other than GeoGebra. The question remained how Mr Magwe managed to use GeoGebra the way he was able to.

Mr Magwe mentioned that most of the features of GeoGebra that he was able to use were because of videos he had watched on YouTube and the training manual. From the YouTube videos, he was able to see how specific GeoGebra features were being used.

> *You know, sometimes when I want to use GeoGebra, maybe I check the manual that was given by the Department. But, most of the time, I check YouTube videos. They will show you how to do most of the things on GeoGebra.*

From the discussion with Mr Magwe, it was evident that schools were receiving many ICT tools from private entities such as Vodacom and the local mines. However, there appears to be minimal training and support for teachers in terms of how they could use these resources to improve the teaching of mathematics.

### 4.4.2 Lesson observation – Mr Magwe

The data below have been derived from the non-participatory observation of Mr Magwe's mathematics class teaching with GeoGebra software. Particular attention was paid to the mathematics content, his teaching practice and, most importantly, how he integrated GeoGebra in teaching the chosen mathematics topic.

#### 4.4.2.1 Introduction

The lesson observation taught by Mr Magwe started with a pre-observation interview to gain an understanding of the mathematics content to be taught, the ICT tools that relate to GeoGebra that he had prepared to use, the expected prior knowledge and any misconceptions on the taught content.

During the pre-observation interview, Mr Magwe indicated that he would be teaching a lesson on functions to Grade 10 learners, focusing on different kinds of graphs. He mentioned linear, parabola, exponential and hyperbola graphs, but indicated that he would not focus on all types of graphs. When asked about the learners' prior knowledge, he mentioned that he expected the learners to know about the x-axis and y-axis and relevant information about the gradient on the graph. He, however, expected them to have misconceptions about the facts pertaining to the increasing and decreasing values along the negative x- and y-axes. Mr Magwe was further asked about the ICT tools that he was going to use with GeoGebra in his lesson, and he mentioned that he was going to use the projector, laptop and whiteboard.

#### 4.4.2.2 Teachers' practices in the teaching of mathematics using GeoGebra

Mr Magwe presented a lesson to Grade 10 learners on the functions topic. The lesson started with Mr Magwe making the learners aware that they were having a special lesson, which included the integration of some technology. He told the learners that they would be looking at different types of graphs. Mr Magwe introduced the lesson by writing on the board: "Linear graphs, Parabola, Exponential, and Hyperbola." He explained that the introduction in functions started with linear graphs, which they would have covered in the lower grades. Mr Magwe further explained that the functions topic started with linear, parabola, exponential and then hyperbola. He made an interesting reference to the linear graphs as the foundational concepts of the graphs. Mr Magwe then introduced the topic by writing the equation representing the linear graph as follows: $f(x) = x \; or \; y = x$ and $y = mx + q$. He probed the learners' prior knowledge by asking them what they understood by the gradient and the effect of the gradient. However, most of the learners did not seem to know about the effect of the gradient because none of the learners responded and they seemed puzzled. Mr Magwe eventually explained that the gradient referred to the slope, which is the steepness of the line. Mr Magwe got deeper into the content by introducing linear graphs.

To illustrate the linear graphs, Mr Magwe referred to the linear equation ($y = mx + q$) he had written on the board. He went on to talk about the value of the gradient as being the coefficient of $x$. He asked the learners whether they knew what happened when the value of the gradient changed. From the fact that none of the learners responded, I concluded that they did not know. Mr Magwe went on to explain that the gradient represented the steepness of the slope of the graph. He told the learners that when the value of $m$ increased, the steepness of the graph increased.


**Figure 4.1: Picture taken during non-participatory observation, illustration of introduction of linear graphs**

From ***Figure 4.1***, it was clear that Mr Magwe was familiar with the content topic and pointed out the critical variables in a linear equation. The various linear graphs that are illustrated in the figure above are the parade of the change in gradient and the meaning of the steepness of the graph. He then went on to the integration of the

GeoGebra software to demonstrate to the learners the impact of the change in gradient $(m)$. The analysis follows below.

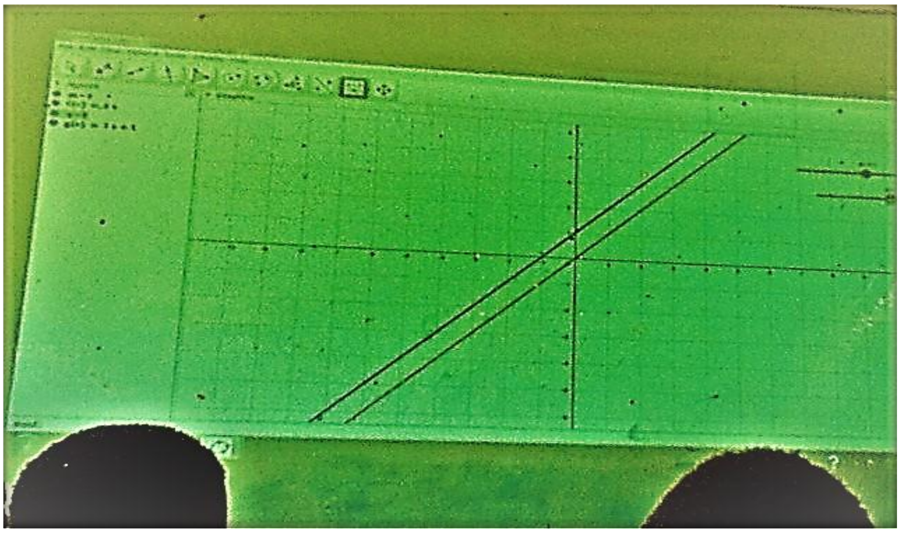

**Figure 4.2: Picture taken during non-participatory observation, illustrating linear graphs using GeoGebra**

During the demonstration of linear graphs on GeoGebra, as indicated above, Mr Magwe told the learners about the key tools that were available within the software to draw a linear graph. He further explained to the learners that multiple graphs could be plotted on the Cartesian plane using GeoGebra. He told the learners that he was going to demonstrate the impact of the value of the gradient. He drew the first graph, where $m = 0$, which is illustrated in ***Figure 4.2*** above as the line at $(0,0)$.

Mr Magwe drew another linear graph where the value of the gradient changed and there was a $y - intercept$. He illustrated various values of the gradient, illustrating the change in the slope of the graph with every changing value. Mr Magwe asked the learners what they were noticing with every change in value. One of the learners pointed out that the value of the gradient had an impact on the steepness of the graph and that the graph came closer to the y-axis with the increased value of the gradient. There was some commotion in class as the learners appeared fascinated by the change. However, they were not provided the opportunity to explore the use of GeoGebra themselves. Some learners seemed lost when the lesson was presented, as they sat quietly and were not engaging with what was going on in class. On the other hand, some learners were shouting in excitement, asking the teacher to try different values so they could see the impact of increasing and decreasing values.

After some demonstration on GeoGebra, Mr Magwe went on to show the learners how they could calculate the value of the gradient, given two points of the graph (***Figure 4.3***). He explained that at least two points represented a linear graph, namely $(x_1,y_1)$ and $(x_2,y_2)$. The image below illustrates the two points as follows: $(2,4)$ and $(7,12)$.

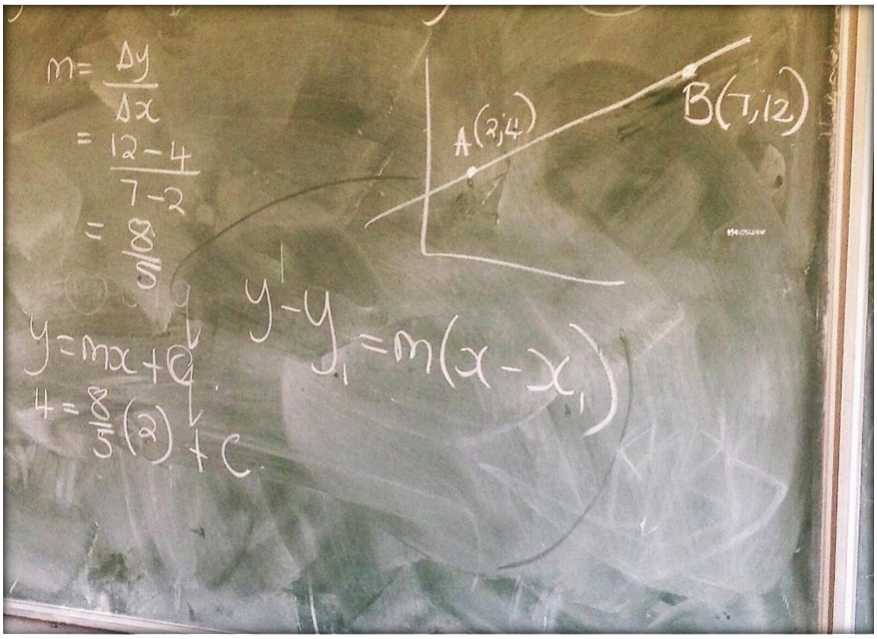


**Figure 4.3: Image taken during non-participatory observation, illustrating how to find the gradient of the line, given two points**

Mr Magwe explained the y-intercept concept. He told the learners that the y-intercept represented the value of y when $x = 0$, which was the point where the line cut through the y-axis. Hence, the image above illustrates the calculation of the gradient and the illustration of the y-intercept, as well as how to obtain the value thereof. Hunde and Tacconi (2013) are of the opinion that the successful use of ICT entails teachers to combine technology with their knowledge of pedagogy, content and context. It was evident that Mr Magwe was confident about the linear graph concept and using mathematics correctly. He demonstrated a good understanding of linear graphs and connecting the concept with the GeoGebra software.

To illustrate the parabola graphs, Mr Magwe introduced the topic of parabola on the board first and then moved on to integrating GeoGebra (***Figure 4.4***). He made an input of the equation $y = 1x^2$, stating that the (1) was an invisible (1). Mr Magwe told the learners that the positive invisible (1) meant that the gradient was positive. He also referred to the equation $y = -x^2$ with the invisible (1), which is negative. He then drew the parabola graph on GeoGebra with a positive gradient.

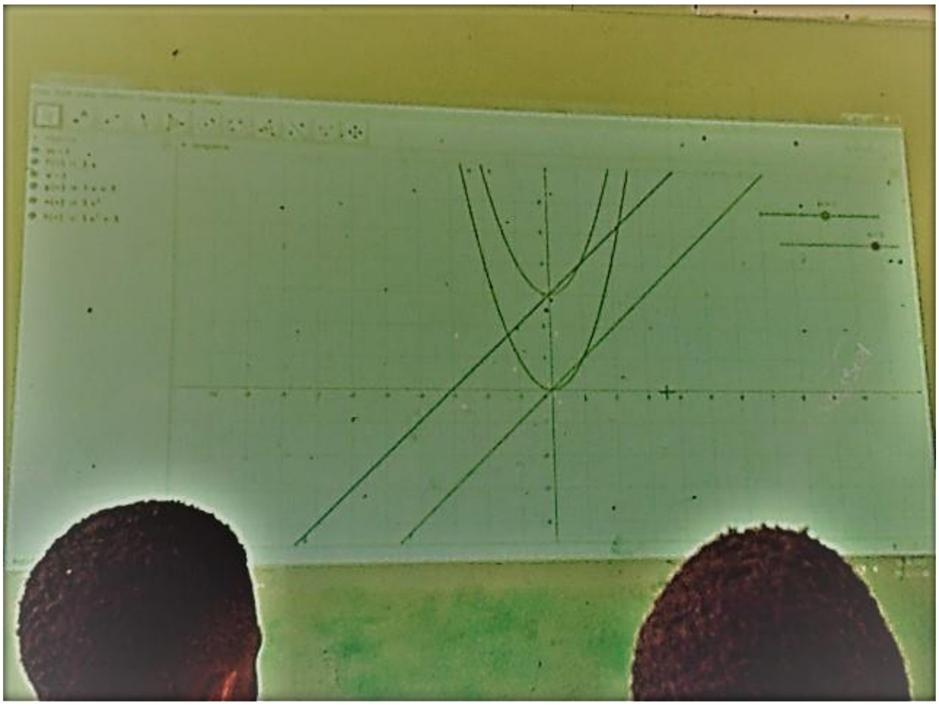

**Figure 4.4: Image illustrating the picture taken during non-participatory observation of the parabola graph using GeoGebra**

Mr Magwe wrote on the board again, $y = ax^2$, and then further:

$$2ax = gradient$$

$$x = variable$$

He explained to the learners that the gradient of the parabola was also the coefficient of $x^2$and that the value of $a$ had an impact on the shape of the graph. For example, the shape of the graph is dependent on whether $a$ is negative or positive. Mr Magwe further explained that when drawing a parabola graph, it was important to determine the value of $x$. He then demonstrated the graph on GeoGebra (***Figure 4.4***) when he drew the graph $y = x^2 + 3$. However, he did not talk about the complication of finding the value of $x$ in the given equation.

#### 4.4.2.3 Instructional practices or strategies

##### a) Teaching strategies

The traditional teaching method is about the textbook being the source of knowledge and learners depending on the teacher to transmit knowledge. However, the 21st-century era demands that the teacher guides learners to become actively involved in their learning. Learners are encouraged to construct knowledge using the information that they already have and use the educational tools at their disposal to develop reasoning and problem-solving skills. UNESCO (2012) refers to the role of the teacher as that of a facilitator, where the teacher aims to assist learners to achieve their educational goal. During the lesson, Mr Magwe was leading the lesson and the learners were listening. He occasionally engaged them by asking questions. There was no opportunity for the learners to engage with one another or to explore the GeoGebra software. The lesson lacked collaboration among the learners, and the teacher did all the talking for most of the lesson.

Karami et al. (2013) hold a different perspective to Mr Magwe's as they advocate for a learner-centred teaching strategy, especially when technology is part of a lesson. The integration of technology is known to encourage deviation from the traditional teaching practice that was adopted by Mr Magwe. Technology is known to promote active and collaborative teaching and learning that build on the learners' existing knowledge.

##### b) Management of assessment

Assessment is an essential aspect of learning, where learners demonstrate their understanding of the learnt concept. In turn, the response that learners give to the assessed work gives teachers an indication of whether learning has taken place or where learners are struggling in understanding the concept.

Mr Magwe requested the learners to take out their classwork books and calculate the gradient of the graph. He asked the class whether they remembered what the gradient was. One learner referred to the gradient as the change in y over the change in $x$. This was not the correct usage of mathematics terms because the "over" that the learner was talking about means “divide by”. The teacher accepted that answer as correct; yet it was not correct. One of the learners asked whether the value of q from the equation $y = mx + q$ was always positive. Mr Magwe responded by telling the learner that $q$ referred to where the line cut the y-axis and it might be a positive or a negative value. Mr Magwe did not seem to link the learner’s question to a lack of understanding of the y-intercept or the Cartesian plane. The Cartesian plane has both a negative and positive y-axis. Therefore, the line cutting through the y-axis will be represented by a negative or positive $q$.

Mr Magwe also asked the learners about the formula that they could use to calculate the gradient and the formula they could use to get the equation of the graph. One of the learners quickly put her hand up, and before Mr Magwe could even choose any learner, she said: “y minus y one, equals to m, brackets, x minus x one.”

The equation mentioned by the learner can be represented as $y - y_1 = m\,(x - x_1)$. Mr Magwe further asked the learners to find the equation of the linear equation through the given the two points: A (8,7) and B (5,4). Some learners were taking too long to find the solutions and time was up for the lesson. Below (***Figure 4.5***) is an example of the solution from one of the learners.

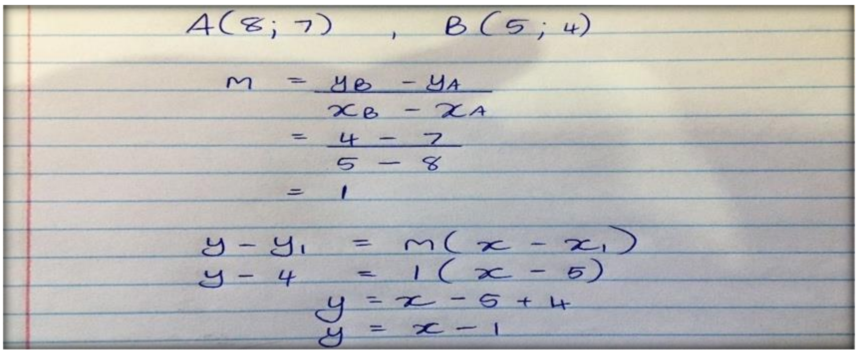


**Figure 4.5: An example of the solution by a learner during lesson observation**

#### 4.4.2.4 Teachers’ challenges in the integration of GeoGebra in the teaching of mathematics

During the pre-observation interview, Mr Magwe indicated that he would use the projector, the laptop and the mobile whiteboard as the ICT tools to conduct the mathematics lesson. However, when the lesson was about to begin, there was no electrical extension cord to connect the mobile whiteboard. Mr Magwe commented that the school did not own an electrical extension cord, but one teacher normally brought it to school. Unfortunately, the teacher forgot to bring the extension cord that day. The class wall was used instead because it was impossible to use a mobile whiteboard. Chigona et al. (2014) argue that the main challenge in the integration of technology in South African schools is not the absence of technology but the lack of crucial basic resources, such as electricity; consequently, teachers feel disempowered in the process. Mr Magwe demonstrated a positive attitude by improvising when the mobile whiteboard could not be used.

Throughout the lesson, Mr Magwe was trying his best to use GeoGebra. However, at times, he struggled with inserting the right command on GeoGebra. He would persist until he got it right. During the post-observation interview, Mr Magwe indicated that he had not used GeoGebra in a while. He reiterated what he had said during the semi-structured interview, namely that the workshop they had attended as part of training on the integration of GeoGebra had been too short. Xu (2017) also attests to the view that PD is a vital aspect of the integration of ICT software in a teaching environment. Mr Magwe further stated that GeoGebra creates a positive learning environment, and learners can visualise the abstract aspect of mathematics.

> *Ya, Ma'am … I am sure you also saw … Learners were curious about what we were talking about in class. I mean, they wanted to know about the gradient. It's not about drawing the graph on the board. But even time is saved. GeoGebra is good. The other problem … it would be nice if there was a computer lab and learners can go and try some of the things that GeoGebra can do.*

## 4.5 Case 2: Mr Sebaya

### 4.5.1 Interviews – Mr Sebaya

#### 4.5.1.1 Background

Mr Sebaya has six years' teaching experience, which includes teaching mathematics, natural science and technology at different schools located in different provinces in South Africa. He taught in three provinces in South Africa, namely the Northern Cape, Mpumalanga and, currently, he is teaching in North-West. Mr Sebaya has taught a wide variety of grades from Grade 8 to 12. Mr Sebaya currently teaches mathematics, and technology at his current school. He holds a BEd Honours degree, a PGCE in Natural Science and Mathematics and a BCom Statistics degree. Mr Sebaya's experience is diverse, as he has taught at a variety of high schools in different provinces in South Africa. I asked him about his qualifications and teaching experience and he explained as follows:

> *Qualifications? Uhm … BComm in Statistics in 2012 in UNISA, Pretoria. And then PGCE in natural science and mathematics, FET. And PGCE, 2014, UNISA. And my Honours also with UNISA. I have been a teacher since 2013. The first two years, I taught in Northern Cape, in a high school. While I was busy with PGCE, I taught maths, science and business studies. Then after, I taught in Mpumalanga. There I taught maths again, life science, life orientation. Now I teach in North-West, here. I teach maths and technology. You can say I have tried all provinces.*

It is evident that Mr Sebaya has had a wide exposure to teaching mathematics, science and technology. He has had diverse experiences from different high schools within three different provinces and this has positively shaped his teaching profession in mathematics teaching and technology.

When asked about his experience of teaching mathematics at his current school, he indicated that there were three teachers who taught mathematics and science in the whole school. He added that teaching mathematics at his school was difficult, especially in the lower grades of the school – Grades 8 and 9. Learners come from primary school with a huge gap in mathematics knowledge. Learners in Grade 8 may not know the mathematics concepts taught in Grades 5, 6 and 7.

> *Yoh! It was difficult [teaching mathematics at his school]. I even though of leaving the subject [mathematics]. Yeah … especially in Grades 8 and 9. Learner's performance was very poor. Mhh … you know ... in Grade 8 and 9, learners are struggling, they are struggling, yes. In a class of 60 like sometimes the best learners are few, very few like less than 10. And I found out that the gaps that they have are just too big. I was surprised myself because I would sometimes give them … let's say … I was in Grade 8 and try to give them Grade 7 works to check if I can see where the gaps are; some couldn't even do it. Then you give them work from Grade 5, Grade 6 ... I don't know ... I don't know where the problem could have started.*

Mr Sebaya further mentioned he was discouraged by learners' lack of resources that could be acquired easily, such as calculators. Most learners in his school do not own a calculator, and that can be disruptive when he plans an activity that requires a calculator.

> *Sometimes, you find that most learners are writing a mathematics test and over 90% of them don't have calculators. Only five calculators in a class and now they have to borrow each other's. Time is wasted. It's hectic …*

*It's so discouraging. You say: "Take out your calculator." Only a few learners have calculators.*

I probed Mr Sebaya about other factors that he thought had an impact on the mathematics performance at his school. He mentioned that the school had a problem with regard to irregular class attendance and some learners being habitually absent.

*Yes, even now, like there is this learner [who] at some point wanted to go home earlier. And when I asked "Okay, what are you going to do?" … she said: "No, I have to go to the clinic." "Are you sick?" "No, for family planning." "It's like, 'what family?'" But what can I say; she has to leave. And what about school? She will miss the lesson.*

Mr Sebaya continued to explain that a lot of social factors were affecting learning at his school. He exemplified by narrating that some learners were continually using contraceptives to avoid becoming pregnant from possible incidents of rape.

*One learner is in Grade 9 … she was like: "No, I am living around a tavern and it's always busy. You don't know what to expect, what if somebody rapes me one day, what would I do with a child? So, I have to be safe, all the time because I don't want that to happen." That was her reason.*

*You know! When learners don't come to class regularly, then you have problems in a subject like maths. The topics link to each other*

The quotation indicates some of the social ills that learners are confronted with that form the contextual environment that has an impact on teaching and learning. Mr Sebaya indicated that these social challenges affected the teaching and learning of mathematics because the learners did not attend class regularly.

Mr Sebaya mentioned that the lack of consistency in class attendance was a challenge. Mr Sebaya explained that his school was experiencing a high volume of teenage pregnancies, where learners in Grade 8 fell pregnant and consequently failed to keep up with schooling. There was also media coverage in the South African news that there was a vast scourge of pregnancies in North-West with young girls being impregnated by older men (SABC, 2019). This recent media coverage on pregnancy is in line with Mr Sebaya's concern about the high teenage pregnancy rate at his school, which has an impact on the teaching and learning of mathematics.

*Yah … Learners don't come to school all the time here. I mean, girls in Grade 8 are pregnant. We had a few pregnant girls this year, even from Grade 8. What can you do when a learner is pregnant? They sleep, they* *can't concentrate. Sometimes, they don't come to school. Eish! What can you say?*

Mr Sebaya further explained that some of the parents were very young to be parents of learners in high school. This makes communication challenging at times, especially when learners are not performing. Furthermore, the element of discipline is lacking.

*You know, I'm 35 years and there are parents that are younger than me and their children are going to Grade 10, 11, 12. Yes, and now the learners in Grade 8 and 9 … like this year, we have so many kids who gave birth. But some mothers of learners in my class are younger than myself, like they are in early twenties or maybe younger. Yah! You will be like, call a parent, [and] another child comes …*

In this year, about 10 learners from the school are estimated to have left school because of pregnancy. As a teacher who has taught at different schools in different provinces, Mr Sebaya cited concern that the learners at the school were, in general, angry. Fights among the learners are common and have an impact on the learning atmosphere in the school. Mr Sebaya argued that the cause of the anger manifesting in violence was an indication of a lack of family support. Okafor et al. (2013) concur that the family environment has an effect on the performance of learners. Hence, Mr Sebaya's view of a lack of family support being a distraction in learning is justified.

*We have a lot. Yoh, it's so sad. It's so sad and the kids are angry, I don't know they are just thieves. Like those ones, they were fighting. I know someone is angry about something and now they are taking it out on another person; that's what I know. You can go there and try to get the real cause and you would find that, no, something is happening at home. So, most of the time, I find learners from this particular school angry as compared to learners from previous schools, and many of them don't have parents.*

Mr Sebaya further mentioned that overcrowding was one of the challenges at the school that mainly came about as a result of accepting all learners who applied. The average class at the school consists of 50 to 55 learners. These numbers start to decrease in Grades 11 and 12.

*In Grade 8, we have 6 classes … I think all in all they are 340 something, so the classes are overcrowded. What we [sic] about 50, 50 something learners in a class. In Grade 9, I think we have around 220, if I'm not mistaken. We have four classes. Grade 10, I am not sure about the number, but I think that they are over 250. We have five Grade 10 classes. When we started the school, we took everyone. Some of them don't pass and the number keeps increasing. It's difficult to teach such big classes.*

Mr Sebaya added another challenge that had an impact on mathematics learning at the school. The school does not have selection criteria but accepts all learners from the neighbourhood. The challenge is that even learners who have never passed a grade in high school are accepted at their school. These learners lack basic mathematics skills.

> *Yeah, because we accepted everyone, so now the majority of those learners in Grade 10, they didn't pass to get to Grade 10. The stayed in a grade until they got progressed to the next grade. From Grade 8 to 9, then fail Grade 9.*

Mr Sebaya stated that the school faced the challenge of dealing with progressed learners. He further mentioned that they had received a circular from the DoE that stated that learners within the Senior Phase may move on to the next grade even if they did not pass within the Senior Phase. Stols et al. (2015) argue that promoted learners are often overaged and have behavioural problems. Consequently, they struggle with school content; hence schools tend to focus on cramming knowledge in matric to allow them to pass. Therefore, Mr Sebaya's concern about promoted learners is justified.

> *Then last year, we got a circular from the circuit manager, that's saying learners who have been in [the] Senior Phase for more than three years should go to Grade 10. So, fortunately we had a lot of those. Even if someone was overage, we didn't care. Like, I think for three years, we didn't care whether a learner passed from Grade 7 or not; we just take them to our school. These learners, you will find them in all sorts of trouble. They will distract the class. Sometimes, you just leave them.*

A follow-up question was posed to establish whether Mr Sebaya experienced any challenges at his school in the teaching of mathematics. Mr Sebaya mentioned that the learners generally did not do their homework, so he insisted that they do their work in class to avoid their not doing their homework. Most research studies indicate that homework is an essential part of learning as a way of assessing whether learning has taken place. Gustafsson (2013) affirms that homework helps with ensuring the repetition of the work done in class and, consequently, encourages learning.

> *I don't know. It's like, if you give them an activity, that's classwork, they do it. If you say it's homework, they say "I'll do it at home" and they don't do it. So that's why if you check their workbooks, even if I know that I don't have enough time, like I don't have enough time to do this as a classwork, please write "classwork".*

Mr Sebaya was further asked what he thought the reasons were for learners not doing their homework. He said that he thought the problem might be psychological or the various challenges the learners experience at home or perhaps some learners were simply too lazy to do their work.

> *Eish! I don't know … These learners, I don't know, maybe the problem is psychological. Learners have problems. Maybe they are lazy to work because they will be like: "But Sir, we have five minutes; let's finish the work at home." And they know they won't. If it's homework, they would be like, "we'll do it at home", and they won't do it.*

Mr Sebaya talked about the performance of learners in mathematics amidst the challenges they face that have an impact on teaching and learning. He mentioned that the mathematics and science departments have worked hard to provide extra classes to Grades 10 to 12 learners. The extra classes allowed them to go through the content for a longer time and that added teaching time. Mr Sebaya perceived the idea of extra classes as a step in the right direction. However, Bernstein et al. (2013) believe that the wide spread of extra classes is often regarded as a response to the poor education in South Africa but extra classes do not address the core problem of poor performance in mathematics education. It is impressive that Mr Sebaya sacrifices his time to give learners extra classes; however, the impact of extra classes remains debatable. Mr Sebaya explained that he used extra classes to teach difficult topics and deal with knowledge gaps.

> *We're trying … we try. I mean, now we have extra classes that we give for maths and science. At least now we can teach one topic over and over. We go through what we did or start a new topic. It depends what is supposed to be taught. When these learners come here, they lack basic maths. So, in extra classes you can go slow on these difficult topics and explain so they understand. If you want to do that in class, it's impossible; the time is not there.*

Mr Sebaya explained that the school had introduced technology in its teaching as a means of improving learner performance in mathematics.

> *We tried everything … WhatsApp groups bring technology in class. We are trying to improve this situation.*

Follow-up was done to establish whether there had been any improvement in learner performance with the advent of extra classes and the introduction of technology. Mr Sebaya replied:

*We start with these learners, seriously, let me see … We started working with them in Grade … I would say like Grade 10, we give extra classes. We just focus on maths and science learners. Yah, I have seen some success stories, like in Grade 12, one of learners ... Uhm she did matric last year ... Yeah, she is in UJ now. She got three distinctions. The two were in maths and science. Yah … we are proud of such learners.*

Mr Sebaya further mentioned that he had also observed some improvement in terms of class averages and individual learner performance in mathematics tests.

*Yeah … If you check the averages, yeah ... even though we are not saying they are doing well, but now the average is now improving, slowly but surely. Some are still failing mathematics. Even the learners in the classroom, a learner can get 10% the last term, but if they get 25% next term, it is still a fail but we recognise … that they have improved. They are improving, yes.*

The evidence above shows that while the school faced a wide range of challenges from teenage pregnancy and learners not being consistent in attending classes to a lack of parental support and learners' lack of resources, the teacher sounded determined to work with the learners to improve their mathematics performance. Even though the literature shows deficiencies in using extra classes as a means of improving mathematics learning, from Mr Sebaya's perspective, they have seen improvement in the learner performance from their intervention strategies, including extra classes.

#### 4.5.1.2 Mathematics CK and pedagogical knowledge

When mathematics software is integrated in the teaching of mathematics, it is essential to establish the mathematics CK of teachers. Koehler et al. (2013) refer to the CK in this context as the teachers' level of understanding of mathematics and how it relates to real-life situations, and being able to use correct mathematics terminology. Mr Sebaya was asked to narrate how he taught various mathematics topics in a South African curriculum. Mr Sebaya said that even though he liked to use the problem-solving strategy, he also advocated for the engagement of learners through working in pairs and in groups.

*Yes, sometimes they would work individually, sometimes in pairs and sometimes in groups. In groups of two and sometimes in groups of five. Yah, this is after I give them a maths problem. Then they work together to find the solution.*

It was clear that he had moved away from the traditional strategies of teaching and incorporated the problem-solving and active learning strategies. He cited an example of a picture of a bridge, explaining how he would engage the learners in their learning. He would use the image of the bridge to help learners understand trigonometry concepts, such as determining the unknown length of the bridge using the principles in trigonometry.

> *So, sometimes we just look at the bridge and say "I see a bridge", but now when they work in a group, then one would say "okay, this part I see trigonometry", and then someone else would also say something; then when they are alone, they would just see a bridge and nothing else. For example, let's say the picture of the bridge shows an angle and on the side of the triangle from the bridge is known. Okay, students will look at the picture and say: "Okay, what is sine of an angle? Okay, opposite over hypotenuse." Then they use the information given in the bridge picture to calculate the side that is not known.*

Research indicates that whenever there is interaction between learners and a teacher, the teacher may ask the learners questions to establish how much prior knowledge they have. The teacher may also pose questions or assess the learners as a way to establish whether they understand what they have been taught. According to Mr Sebaya, sometimes learners find it easy to say that they do not understand anything that the teacher has just taught. In that situation, it is important to ask the learners questions and when they get the answer wrong, he quizzes them to help understand where they are going wrong and encourages them to mention the mathematics terms they have learnt, for example the gradient concepts when they have just been taught about the gradient.

> *No, sometimes I ask, okay, you didn't understand, but can you explain? What didn't you understand? Because sometimes it's not a matter of the learner not understanding, it's a matter of the learner losing concentration. So, you help them come back into thinking about the maths we are doing.*

Mr Sebaya further clarified how he would explain the concept of functions about the gradient. He demonstrated a scenario where the learners might be confused about how the gradient of a linear equation is determined and how he would expect them to make the first attempt and then clarify what he perceived as a challenge.

> *Let's say, if I spoke about gradient. Okay, the gradient of the straight line. I would expect them to mention something about the gradient. For example, I can maybe give them two points of a straight line and ask: "So, how do you calculate the gradient?" Maybe if they don't understand that*

> *the gradient is really change in y divide by change in x, they will mix the points … because they are confused. I will then write the formula and label the y and x points, then calculate the gradient with them step by step.*

The mathematics content covered in the South African high school curriculum includes geometry. I asked Mr Sebaya how he would introduce a topic in geometry to his learners in Grade 10 as an example. He said that he would teach the properties of triangles and then gave an example of the properties of an isosceles triangle.

> *Okay, maybe I am teaching properties of triangles. I would ask learners what they know about an isosceles triangle. Then, maybe draw it. And tell them: "You see the two opposite sides are equal and the angles opposite the two equal sides are equal."*

It was evident from the quotation above that Mr Sebaya had some knowledge of geometry, even though his example lacked depth of understanding of geometry. However, it was the correct representation of the facts of an isosceles triangle.

#### 4.5.1.3 Integration of ICT in the teaching of mathematics

There has been an urgent need to equip South African schools with various forms of technology. Hence the DBE (2012) has provided guidelines to schools for ICT hardware and software. The document provides multiple hardware and software tools that each school in South Africa should have. I, therefore, sought to determine from Mr Sebaya which ICT tools he was exposed to at his school and how he used them in the teaching and learning of mathematics. He stated that the school had laptops for teachers, one projector for the whole school and a mobile whiteboard.

> *Our school? ... Here we have one projector for the whole school. Yah! Almost all teachers have their laptops. There is also a whiteboard; then one that you fold and put away. It's nice because you use it when you need to and you can put it away when you don't need it.*

It was evident that the school had a variety of ICT resources available for the teachers to use as part of teaching and learning. However, it was necessary to establish how Mr Sebaya integrated these ICT resources in his teaching and learning of mathematics.

I asked Mr Sebaya how he used the ICT tools as part of his teaching. He indicated that he stored various teaching material on his laptop, including videos or images that he might want to display in class when he taught.

*We are sometimes given some material to use in class. So, I keep it in [sic] my laptop. I have a lot of videos in [sic] my laptop. In teaching a topic, usually I use videos for introduction before I say anything and then sometimes some of those videos are kind of icebreakers for mathematics. Okay, today I was doing geometry, but sometimes I would just give them just a quick way of multiplying three numbers together.*

Mr Sebaya continued to explain how he used videos as part of his teaching:

*I can play a video, like … I know it won't be part of the lesson but just to activate their minds as a form of an icebreaker. So, yeah, sometimes I use them as an icebreaker and sometimes as an introduction. And, sometimes if I am busy, like maybe doing something, and then the video would be playing.*

It was evident that Mr Sebaya regularly used technology in his mathematics classes. Therefore, I asked him how he used the projector. He mentioned that he used the projector with his laptop to display work from his laptop and videos.

*I use the projector and laptop all the time. Maybe I introduce the lesson. Then I play the video, which [is] like an icebreaker. Sometimes, I have some work from software that I want to display in class; then I use the projector.*

Mr Sebaya further explained that he used the projector regularly in his mathematics classroom; hence sharing the projector with other teachers at the school did not appeal to him.

*I bought my own projector and whiteboard. This thing of sharing is not working. Sometimes you want to use the projector but somebody is busy. So, I bought my own projector and whiteboard. But I don't have a car, so I can't bring my whiteboard to school.*

From the quotation above, it was evident that Mr Sebaya was keen on using ICT tools in his teaching; hence he had bought his own projector and whiteboard to use in teaching mathematics.

*They are performing better; even the numbers, like it's not that significant, but I have seen an improvement. Even learners who didn't want to participate, I remember in Grade 9A because Grade 9A is a problem because it's a naughty class; like every teacher knows that. But we realised that these learners are clever and they perform better than other classes even though they are problematic. Everybody gets excited when they see technology in class.*

From the quotation above, it was evident that the presence of ICT tools had a positive impact on learning, considering the change in learner behaviour in a class that was regarded as a problem class.

Mr Sebaya said that he encouraged his learners to bring in calculators to class. They used calculators to make difficult or complicated calculations. They also use calculators during examinations to calculate faster; hence it is important that they learn how to use calculators during class.

> *I have noticed that it's easy to get learners to bring calculators to class. They are not expensive. So, they will have their calculators. Maybe there is complicated multiplication calculation. They take out their calculators and calculate. Yah … even calculations for the square root. It's easy to use a calculator. Calculators are allowed in an exam. It will save time to make to use [sic] calculator. Otherwise you can't finish.*

Mr Sebaya further mentioned that in as much as he preferred using calculators, the challenge was that only a few learners in each class owned calculators. So, the learners who have calculators have to share, and that can be disruptive in the classroom.

> *So, sometimes, you find that most learners don't have calculators. Like, learners will be writing a maths test and over 90% of them [learners] don't have calculators. You will find that [there are] five calculators in a class and now they have to borrow each other's. Time is wasted. It's hectic. Now, there can be too much talking in class.*

It was good to note that Mr Sebaya was trying to incorporate different kinds of technology into his teaching.

Mr Sebaya commented about the attitude of the learners when technology was used as part of learning. He mentioned that learners became excited about learning when technology was introduced in the mathematics classroom.

> *So, they were like: "Oh, you brought your laptop!" Like, it's just something, they just like it when you are using technology. Before you can do anything, you can see the excitement from [sic] their faces.*

Several research studies indicate that there are challenges that are associated with the integration of ICT tools in the teaching and learning of mathematics. Mr Sebaya said that the biggest challenge was that not all learners had access to ICT tools. He believed that learning with technology would be effective if learners were able to participate in using it.

> *You know when you bring technology to class, learners get excited and they will be asking to touch this and that. So, you can see that's right, there is an interest, but most of them don't have technology at home. I wish, somehow, all learners can have technology … just any. That won't be the same like when they just see it in class.*

Mr Sebaya further indicated that the issue with resources also affected teachers in as much as it affected learners because the teachers had to share one projector for the entire school of 900 learners. That had motivated him to buy his own projector.

> *I would like to see every learner and teacher using technology. It's just that our school is under-resourced and that's why at some point, I was like, no, I am going to buy my own projector. Yes, so I can use it more often and not worry about sharing.*

#### 4.5.1.4 Integration of ICT software in the teaching of mathematics

There was an interest in establishing the practice in the integration of the various software tools to which Mr Sebaya was exposed. The *Guidelines for Schools: ICT Hardware Specifications* (DBE, 2012) gives an indication of the specific minimum software tools that each school is supposed to have, which include, among other things, a word processor, spreadsheet and presentation software and a web browser. Mr Sebaya mentioned that he used different kinds of software to enhance the learning experience of the learners in the classroom. Besides using GeoGebra, he uses Microsoft Word, Microsoft PowerPoint and SAS, a statistics program.

> *Yes, I use different software like Word, PowerPoint sometimes. My first degree is in Statistics, so I like the Stats program called SAS. It is great!*

This study makes a distinction between hardware and software tools. Even though the study focuses on GeoGebra software, it is also essential to consider other software tools available in the teaching and learning environment. Most of the software programs are interrelated, and there was an interest to know how Mr Sebaya used the software tools that he was exposed to. He mentioned that he used Microsoft Word, especially for setting questions papers because it saved time.

> *For Word, I would say I use it for question papers. Like when we set question papers. It is easy to share with other colleagues. For learners, you just print it and that's all.*

It was clear from the quotation above that Mr Sebaya was not using Microsoft Word for mathematics teaching apart from typing question papers that were easy to share with other teachers and easy to distribute among the learners during the assessment.

I asked Mr Sebaya to explain how he used PowerPoint as a part of teaching and learning. He mentioned that he did not use PowerPoint all the time, but he used it to present prepared lessons via his projector.

> *You know with PowerPoint, I don't use it all the time. Yah, but ... maybe sometimes when I have prepared a lesson, I can put it on PowerPoint and then use [the] projector for the class to see.*

Mr Sebaya explained that he was not good with Microsoft Excel and preferred to use a statistics program called "SAS". He liked to use the SAS program for teaching statistics, especially when the learners had to analyse large amounts of data and they needed to calculate the mean and standard deviations.

> *I am not good with Excel. Yes, and for statistics, sometimes when I am dealing with huge data, it's difficult to use a calculator, so I am using such programs for calculating the means, the variables and standard deviation and all that stuff.*

From the quotation above, it is evident that Mr Sebaya has minimal knowledge of software packages that can enhance the teaching and learning of mathematics. He uses Microsoft Word and PowerPoint mainly for administrative purposes and not as part of a mathematics lesson.

#### 4.5.1.5 Integration of GeoGebra and the connection thereof to CAPS

It was important to establish from Mr Sebaya what he thought of the link between the mathematics curriculum as according to the CAPS document (DBE, 2011) and what GeoGebra software could do. Mr Sebaya mentioned he had noticed that there were many topics from CAPS that could be taught using GeoGebra, for example functions, which is an aspect of algebra, as well as geometry and trigonometry.

> *Yah, in CAPS, you have functions, geometry … you have trig. All these topics, one can easily teach them using GeoGebra.*

From the quotation above, it is evident that Mr Sebaya is convinced that there is a connection between the mathematics content for high school that needs to be covered as according to CAPS and what GeoGebra as a software tool has to offer.

GeoGebra software is known to be a versatile tool used to teach various mathematics topics in high school mathematics. Zilinskiene (2014) recommends using GeoGebra for teaching most algebra topics. Despite Mr Sebaya's limited use of GeoGebra, it is interesting that he has incorporated GeoGebra in teaching some mathematics topics. He indicated that he enjoyed using GeoGebra for teaching concepts of functions. Mr Sebaya used GeoGebra to illustrate the concept of the gradient to the learners.

> *Calculate the gradient of the first line and the gradient and the coordinates, but there I just … you know, click, and then it gives me a gradient.*

However, his interpretation of the two lines on the same Cartesian plane was concerning because he thought the multiplication of two gradients would give an indication of the size of the line, whereas the multiplication of the two gradients gives an indication of whether the two lines are parallel or perpendicular.

> *And then they would ask, now this is the gradient of this line, this is the gradient of this line and they can now multiply the two gradients to check if the lines are big or not. But if I have to do that with chalk on the chalk board it was going [sic] to take me some time.*

Follow-up was done to establish how Mr Sebaya used GeoGebra to teach functions. He mentioned that GeoGebra was important in comparing different types of graphs as the learners were able to observe the changes. Venkataraman (2012) affirms that GeoGebra makes learning mathematics meaningful and relatable. Mr Sebaya had noticed that the learning environment changed and improved when learners witnessed the changes from the GeoGebra input.

> *GeoGebra is so good … like in terms of comparison, you need to compare graphs. It's easy to compare different types of graphs and learners are observing. I can see the change in learners; they understand … and that is what I like.*

I continued to probe Mr Sebaya to establish exactly how he taught functions using GeoGebra. He was very excited to explain that most of the time, the learners find it easy to draw graphs but they struggled to interpret them. Therefore, he had found a way of introducing the concepts of the domain and the range. To draw a graph on GeoGebra, it is necessary to specify the domain and the range. This helps learners to give meaning to the concepts. Whenever there are two graphs, learners also struggle to identify when the graphs are equal, whereas with the GeoGebra software, it is easy to identify the equal points of the graph.

*And then we ask them questions based on the graph, like: What is the range of graph of g(x)? Where is the graph increasing? Where is the graph increasing? From what you see, what can you say is the domain or range of the graph?*

Mr Sebaya further explained how he would use GeoGebra to teach functions. He said he could use GeoGebra to interpret the gradient of two lines and that drawing graphs using GeoGebra was easy.

*Okay, let's say we are dealing with two graphs. Because most of the time we combine the two graphs, we combine the two. So, most of the time when learners are given two graphs, as I have said before, now we can interpret, because it's easier for learners to draw the graph using GeoGebra.*

Mr Sebaya mentioned that he also used GeoGebra to teach several aspects of geometry; for example, he had discovered that he could use GeoGebra to illustrate the midpoint theorem.

*Yes, so I didn't train to do this, but as I was playing on GeoGebra, triangles, lines and then I discovered that, oh, I can use this to introduce [the] mid-point theorem.*

Mr Sebaya indicated that he used GeoGebra for illustrative purposes, specifying that the Cartesian plane was often confusing to the learners and he found that GeoGebra was very helpful in helping them to see that the x-axis and y-axis are located in the Cartesian plane. Most learners seem to confuse the location of negative and positive numbers on the Cartesian plane.

*Yes, in Grade 9 because that's where we introduced [the] Cartesian plane, so they can see that this is [the] y-axis, this is [the] x-axis, and I think if learners can get the basics of the Cartesian plane … I think I have had some of the swapping the numbers, the coordinates. So, in Grade 9, that problem is serious. But now if they see that more often on the screen, it helps a lot, it helps a lot because sometimes you find that the whole question … the learner has swapped the numbers. They confuse the positive and negative numbers.*

There is wide research on the impact of GeoGebra in teaching geometry, indicating improvement in learner performance. Mr Sebaya used GeoGebra to teach the properties of the triangle. He would illustrate the sum of the angles of the triangle and quadrilateral and then illustrate that the quadrilateral could be divided into two triangles. He would draw different triangles and quiz the learners about the properties they were observing to help them understand what they were learning.

*The sum of the angles of the triangle equals 180 degrees. Then, when we get to quadrilaterals and now the sum is 360 degrees … so, we usually just draw a quadrilateral, now, because they would be observing and then divide it into two triangles. And then you ask them: "What is the sum of this triangle, the sum of this triangle? 180, this one? What can we conclude about the sum angles of this?" That is easy for them to conclude so that they see what is happening.*

#### 4.5.1.6 Perceptions of teachers on GeoGebra software in the teaching of mathematics

For the purpose of my study, it was interesting to explore Mr Sebaya's perception of integrating GeoGebra in the teaching of mathematics in South African high schools. I then asked him about the conception of his knowledge of GeoGebra. Mr Sebaya mentioned that he had first heard about GeoGebra about two or three years previously from someone from the DoE; he could not remember the name of the DoE official.

*GeoGebra? Eish! I can't remember very well, when I did first hear about it. I think it was two or three years ago. Yah … A guy from the Department came – I can't remember his name – he came and showed us GeoGebra from his laptop.*

I asked Mr Sebaya what he thought of GeoGebra as a mathematics software tool in his teaching. Most researchers think highly of GeoGebra because it brings about a positive learning environment. Mr Sebaya concurred that GeoGebra was a wonderful mathematics software tool that made teaching and explaining easier. Using it, teachers do not have to draw graphs on the board and that can save time, allowing more time for the teachers to engage with the learners.

*Yes, I would definitely recommend it [GeoGebra]. Hmmh … it would make the teaching job easier. They won't have to draw graphs on the chalkboard, and minus one problem. And then it would increase the interaction between the learner and the teacher.*

Mr Sebaya added that GeoGebra was wonderful to bring mathematics concepts to life.

*Yes, and then again, you know learners learn by observing something. So, as they will be drawing graphs and then learners are observing what is happening, it is easier for them to understand.*

I asked Mr Sebaya how he normally used GeoGebra in his teaching of mathematics. He indicated that he sometimes used GeoGebra as a revision tool for the learners in the concepts that they had already learnt in class and to explore and have fun in learning mathematics. Zilinskie (2014) advocates for the use of GeoGebra for experimental work and exploration. Mr Sebaya sounded excited about the potential of GeoGebra, affirming that GeoGebra was a good program.

> *But at the same time, I am refreshing their memories with these formulas and it just came as I was playing around, so I think … actually, I know it's a good program. Look, they can explore different things about maths. They can have fun.*

When I asked Mr Sebaya whether he recommended the integration of GeoGebra in teaching, he indicated that it would work best if the learners also had access to GeoGebra or could install it on their smartphones. However, he quickly added that it would not work for Grade 8 to 10 learners because most learners in those lower grades did not have smartphones. The limited number of computers and the inadequate ICT infrastructure are some factors that impede the integration of technology in South African schools (Akbulut et al., 2011). However, having GeoGebra installed on smartphones for Grade 12 learners might work because the school had made it compulsory for Grade 12 learners to own smartphones.

> *Yah, if learners could have GeoGebra. Okay, Grade 10, 9, 8. But, like I said, Grade 8, 9, 10, most of them can't afford smartphones. So, yeah, we actually have observed the classes because we don't want to put the learner in the state that they feel neglected. But maybe in Grade 12, we can have smartphones and then they can download GeoGebra.*

Mr Sebaya further indicated that even though he would recommend GeoGebra in the teaching of mathematics, he felt that one of the challenges facing the integration of GeoGebra was the fact that the learners did not have access to computers and, therefore, could not explore GeoGebra by themselves. It was therefore evident that the limitations with regard to learners having access to computers had a negative impact on the integration of GeoGebra.

> *Yah, it would be nice if learners can have computers. Maybe if we had [a] computer lab, because we could have a lesson and learners can do some work on GeoGebra. They could do classwork. I think that would be interesting.*

From the conversation with Mr Sebaya, it was evident that he thought highly of GeoGebra as a mathematics software tool that could enhance teaching and learning in a high school mathematics classroom. He highlighted the lack of resources as a challenge in the integration of GeoGebra.

#### 4.5.1.7 PD support

In South Africa, an established policy and framework guide the development of teachers in the integration of ICT tools. There is a need for teachers to develop their pedagogical foundation when integrating technological tools into their classrooms. There was, therefore, a need to establish the kind of PD that was available to Mr Sebaya and other teachers in the integration of GeoGebra in teaching mathematics. He mentioned that he could not call their training in GeoGebra "training" because they had only been summoned to the principal's office to meet the official from the DoE who told them about GeoGebra. He further mentioned that there was no introduction, as they all congregated around the official's laptop.

> *Hey, we were busy that day, we were busy, and I don't remember whether it was a meeting or what but it was very busy and the principal was like "just go to him for a few minutes", and then he just gave us pointers there and there. So, it wasn't really a training; we didn't do much. We just sat around the laptop and the gentleman just went through the whole thing quickly.*

A follow-up question was posed to establish exactly what they were shown about GeoGebra in that short space of time. Mr Sebaya indicated that the official briefly showed them that GeoGebra could do interesting things in geometry, trigonometry and the drawing of lines. It was quick, but it made them curious to want to know more about GeoGebra.

> *Yah, it happened so quickly, but I remember thinking, this is good. You could see geometry, trig and drawing of lines. It was interesting. I just wish it could have been planned nicely.*

In the South African education system, there are policies that encourage the development of teachers in integrating technology into their teaching. Teachers may gain knowledge of how to integrate technology through PD that is targeted towards technology (Watson, 2015). From the conversation about the training received, it is clear that the training has not been planned well; it has left the teachers curious to work on GeoGebra, but the training was limited.

A follow-up question was asked to establish if there was any ICT training available for teachers other than GeoGebra.

> *Yah, we sometime have ICT workshops. Like last week, I was not around and attended the training. But there was no workshop training for*

*GeoGebra. It was that one gentleman from the Department who gave us the GeoGebra [training].*

Mr Sebaya explained that there was no follow-up training on GeoGebra even though they had subsequently attended other ICT training sessions. However, he and the other teacher who had received training with him worked together in integrating GeoGebra in their mathematics lessons.

> *We have not seen him since that day. It was myself and Mr Dingane who received the software. I sometimes ask him when I get stuck. But to be honest, even though … I know that GeoGebra is good.*

Mr Sebaya emphasised that his knowledge of GeoGebra was limited and he believed that he was not fully aware of what GeoGebra could do to enhance a mathematics lesson.

> *But I don't, I know less than 50% of what I can do with GeoGebra.*

He, however, indicated that he had grown to like GeoGebra even though he did not feel confident to use it. Despite the limited training he had had in integrating GeoGebra, Mr Sebaya demonstrated a very positive attitude towards teaching using GeoGebra. He even mentioned that he was looking forward to a time when he could construct his own diagrams using GeoGebra.

> *If I can see myself being able to draw my own diagrams, any diagram, then I would say that I am satisfied.*

This shows the limitations in the PD of teachers in integrating GeoGebra. The software was accompanied by manuals, but there were limited training and no follow-up on any challenges that teachers could have experienced.

Follow-up was done to establish the kind of support that was available to Mr Sebaya and other teachers. Mr Sebaya mentioned that an organisation called "Teach South Africa" had donated videos to the school that they used as part of teaching.

> *So, there is this organisation, Teach South Africa, and they once gave me a whole bunch of videos to facilitate the learners, to facilitate teaching. So, I have still kept them and I have a number of the videos in my laptop.*

Mr Sebaya continued to give the details of the support they had received from Teach South Africa. He mentioned that the videos contained teaching resources in trigonometry and geometry that explained mathematics concepts from the perspective of other people.

> *… for trig, it's just so many things. Trig, geometry and some are the lessons presented by other people. And then some explanations, deeper explanation of certain concepts. It is different presenters. Some are really good; they explain maths topics well.*

### 4.5.2 Lesson observation – Mr Sebaya

The data below have been derived from the non-participatory observation of Mr Sebaya's mathematics class teaching with GeoGebra software. Particular attention was paid to the mathematics content, his teaching practice and, most importantly, how he integrated GeoGebra in teaching the chosen mathematics topic.

#### 4.5.2.1 Introduction

The observation of the lesson taught by Mr Sebaya started with a pre-observation interview to gain an understanding of the mathematics content to be taught, the ICT tools relating to GeoGebra that he had prepared to use, the expected prior knowledge of the learners and any misconceptions on the taught content.

During the pre-observation interview, Mr Sebaya indicated that he would be teaching Grade 11 learners about the properties of triangles, the transformation of the triangle and the calculation of the length of the line. He expected the learners to have basic knowledge about the properties of triangles, such as the sum of the angles of a triangle is equal to 180 degrees. When asked about his expectation of learners' misconceptions, he mentioned that it was an easy topic and he expected the learners to grasp the concept fairly easily. I asked Mr Sebaya about the ICT tools that he was going to use as part of his lesson, which would also include GeoGebra. He said that he would be using his laptop, a projector and a mobile whiteboard. Mr Sebaya mentioned that the school had only one projector and one whiteboard, which all the teachers had to share. On the day of the non-participatory observation, Mr Sebaya was using his own projector that he had just bought. He connected all the required ICT tools with the learners also taking part. There were challenges in connecting the new projector. However, Mr Sebaya handled the situation very calmly and although the lesson was delayed, he demonstrated confidence in using technology.

#### 4.5.2.2 Teachers' practices in the teaching of mathematics using GeoGebra

Mr Sebaya started the lesson by reading the aim of the lesson from the textbook. The aim of the lesson was to learn about different properties of different triangles, similar triangles, the midpoint theorem and the distance formula. He explained to the learners that GeoGebra would be used for the lesson. The lesson started with Mr Sebaya drawing the different triangles using GeoGebra. He then quizzed the learners on what they were observing and then told them which types of triangles they were. Then he drew their attention to the proportion of the sides of the triangle and told them that they could calculate the sides of the triangle using the distance formula:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

Most of the learners in the class had calculators, which Mr Sebaya encouraged them to take out because they would need to use them during the lesson. To illustrate the identification of the properties of an isosceles triangle, Mr Sebaya drew a triangle using GeoGebra (***Figure 4.6***). The triangle was drawn with two sides that were equal, and one angle was equal to 90 degrees. The exterior and interior angles of the base of the triangle were also identified. Mr Sebaya used the drawn triangle as the discussion point. The two base angles were equal in size, namely 45 degrees. Therefore, the other angle was a right angle because the GeoGebra measurement identified it as 90 degrees. However, Mr Sebaya also brought to the learners' attention that the sum of the interior angles of a triangle is equal to 180 degrees. So, if the two base angles are both equal to 90 degrees, the remaining angle will be:

$$180° = 45° + 45° + unknown\ angle.$$

$$Unknown\ angle = 180° - (\ 45° + 45°) = 90°$$

From the same triangles, Mr Sebaya measured the two sides that were opposite the equal base angles. The two opposite sides were equal to each other. Then the properties of the triangle fitted the description of an isosceles triangle.

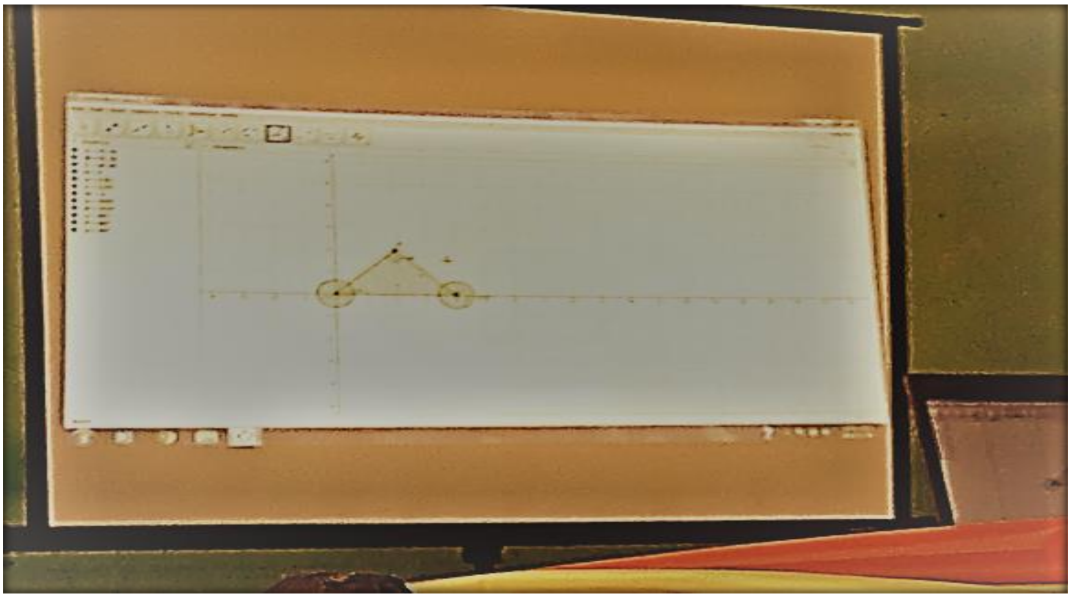

**Figure 4.6: Picture taken during class observation with Mr Sebaya to illustrate the properties of an isosceles triangle**

The isosceles triangle was identified from the two equal base interior angles. The one right angle in the triangle (***Figure 4.6***) characterised the triangle as a right-angle triangle. It was also determined that the size of the angle around the point was equal to 360 degrees.

Mr Sebaya introduced the midpoint theorem by drawing another triangle attached to the first triangle, as depicted below in ***Figure 4.7***. He drew the learners' attention to the essence of the midpoint theorem – that it exists when the line joining the midpoints of two sides of a triangle is parallel to the third side and half of the length of the third side.

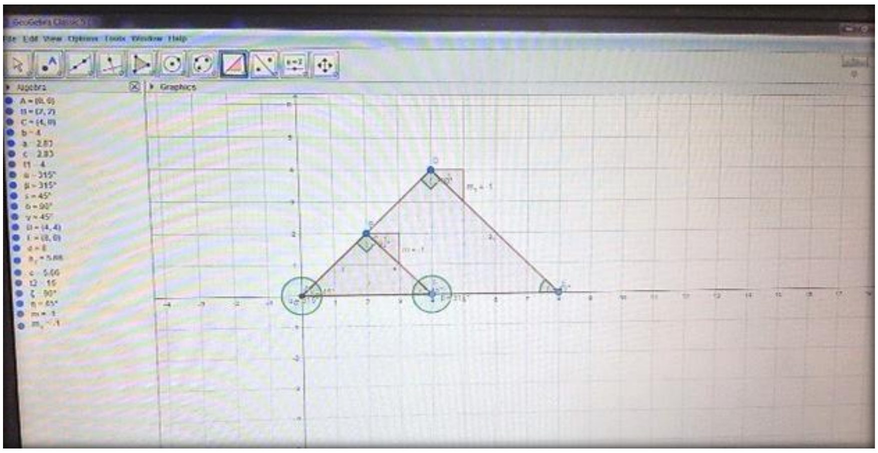

**Figure 4.7: Picture taken during class observation of the illustration of the midpoint theory**

The second triangle, as illustrated in ***Figure 4.7*** above, was drawn as an extension of the first triangle to illustrate the midpoint theorem. The gradient of the two lines was measured and with the understanding that two gradients would be equal if the two lines were parallel to each other, all the properties of the midpoint theorem were confirmed. The distance of the lines was also calculated using the distance formula to check whether the found value was correct as according to GeoGebra.

#### 4.5.2.3 Instructional practices or strategies

##### a) Teaching strategies

The traditional teaching method is about the textbook being the source of knowledge and learners depending on the teacher to transmit knowledge. However, the 21$^{st}$-century era demands that the teacher guides learners to become actively involved in their learning. Learners are encouraged to construct knowledge using the information they already have and use educational tools at their disposal to develop reasoning and problem-solving skills. UNESCO (2012) refers to the role of the teacher as that of a facilitator, where the teacher aims to assist learners to achieve their educational goal. During the interview, Mr Sebaya mentioned that he preferred the problem-solving strategy when teaching mathematics to his learners. He indicated that he often presented a problem and then the learners would have to find the solution using their prior knowledge. During the non-participatory observation, the learning atmosphere was very positive. He asked the learners what they knew about the size of the angle around the point. Some of the learners referred to the interior angle, saying it was 45 degrees. One of the learners stood up and showed the other learners that it could only be 360 degrees. The discussion continued, with some learners asking Mr Sebaya to check the length of the opposite sides of the triangles when compared to the other triangle that had just been added.

**b) Management of assessment**

During the non-participatory observation, general assessment was done during the lesson. For example, Mr Sebaya asked the learners to determine the size of the third interior angle when they knew the sizes of the two interior angles. The learners took their calculators and started calculating the size of the unknown angle. When Mr Sebaya talked about the base angles of the triangle, one of the learners talked about the angle of inclination. Mr Sebaya guided the learner to understand that the discussion was about the angles at the base of the triangle. During the lesson, learners were also given the opportunity to calculate the distance between the two points and compare their solutions with the solution determined from GeoGebra.

#### 4.5.2.4 Teachers' challenges in the integration of GeoGebra in the teaching of mathematics

During the semi-structured interview, Mr Sebaya was optimistic about GeoGebra in communicating mathematical ideas in the teaching and learning environment. However, he was not very confident in using GeoGebra, although his lesson included GeoGebra from the beginning until the end. The lesson included the identification of different triangles that were drawn using GeoGebra. The learners were able to see live that the two opposite sides and base angles of an isosceles triangle are equal. The midpoint theorem was also conceptualised using GeoGebra and confirmed the parallel lines using the knowledge that they had that two lines were parallel if the gradients were of equal value. The distance between the points was also calculated and the value was confirmed to be correct using the GeoGebra software.

Teachers' (negative) attitude towards technology has been noted by various researchers as one of the main challenges in the integration of any form of technology in teaching and learning. To the contrary, Mr Sebaya displayed a positive attitude towards the use of GeoGebra. The entire observed mathematics lesson was conducted with the inclusion of GeoGebra. Even though he could have explored various triangle properties in teaching but only focused on the isosceles triangle, there was a spirit of enthusiasm in his use of GeoGebra.

## 4.6 Case 3 – Mr Golenyane

### 4.6.1 Interviews – Mr Golenyane

#### 4.6.1.1 Background

Mr Golenyane has been a teacher for nine years. He has been involved in teaching mathematics, natural science and physical computer science. He has taught at a variety of high schools within the North-West Province and has been teaching at his current school for three years. Mr Golenyane's experience is diverse, as he has been teaching mathematics for nine years to a wide variety of grades.

> *Uh, to start with, I have done computer science, majoring in BSc in Computer Science and Information System. Then after that, I have decided to come and I had to do PGCE, which is one of the qualifications in teaching. And I have teaching mathematics for a period of nine years for now. Yes, and I have taught Grade 8, 9, 10, 11 and 12 in mathematics. I have been teaching since 2011. Yes, I was teaching, also I was teaching NS Grade 8 and 9 and physical science Grade 10.*

It is evident that Mr Golenyane boasts a wealth of experience in teaching mathematics and science, which has positively shaped his teaching profession. He has a diverse background from teaching different grades at different high schools in South Africa.

When I asked him about his experience of teaching mathematics at his current school, he indicated that he enjoyed teaching at his school, apart from the challenge that most learners struggled with mathematics, especially in Grade 8 and 9.

> *It is not a problem teaching mathematics; the problem is that when I arrived here, I realised that the learners that I got, they were not having that background, especially from Grade 8 and 9. They could not do simple maths, like maths done in Grade 6 and 7.*

Mr Golenyane talked about what could be affecting the learner performance at his school. He mentioned that learners come from primary school with a huge information gap. Some learners cannot even do simple multiplication and this poor performance in the early grades has the long-term consequence that these learners can never do pure mathematics.

> *You know … I'm not sure what the problem is here. But I think the problem is in primary school. Yah, some of the learners struggle with just simple*

> *multiplication. Now, the sad thing [is] they can never do pure maths if they pass at level 1 or 2.*

Mr Golenyane further indicated that the other challenge that they experienced in the mathematics performance at his school was that the contact time was too short. Learners who do not have basic mathematical knowledge need more time and not only an hour.

> *Time is a big problem. You know, you cannot teach mathematics and not go an extra mile because contact time … an hour is not enough. More time is needed to be able to help these learners.*

I posed a follow-up question to establish whether they had found a solution to the challenge of non-performance at his school. Mr Golenyane replied that the school decided to offer extra classes that were compulsory for all learners.

> *Yah, we decided to have extra lessons with all learners. That is the first thing, you cannot teach mathematics and not go an extra mile because contact time is important; an hour is not enough.*

Mr Golenyane explained how they handled the extra classes. He mentioned that they combined the learners according to their performance in mathematics. For example, learners who are performing well, at level 7, were put together with learners who were struggling with mathematics.

> *So, if you go an extra mile, now that means you are going to understand these learners; oh, I am having the seven learners that are having level 4s. Then you group those learners in terms of their abilities; therefore, that is where you can see that these learners, I can teach them this or this.*

Mr Golenyane further explained that as part of the solution, they decided to move the teachers around. He mentioned that he had observed that the older teachers were more patient working with struggling learners than young and inexperienced teachers.

> *In fact, those old, old teachers that have been doing maths long ago, the old ones that have the range of 40 to 60, they do have that perseverance but us, the younger ones, the ones that are between 24 and 35, we turn to be good in higher grades, but not [with] these smaller kids.*

He continued to explain their strategy of moving teachers around and mentioned that the focus was mainly on Grades 8 and 9. In these grades, they put teachers who are useful in mathematics and science to assist the learners to choose mathematics when they have the opportunity to choose in Grade 10.

*Yeah, we are focusing on Grade 8 and Grade 9, and then from there, we know that in Grade 10, you can choose to do maths. If you do have a teacher who is good in mathematics and also can teach NS, then we put them in these lower grades. Then that will channel them to this stream of maths and science.*

#### 4.6.1.2 Mathematics CK and pedagogical knowledge

CK is an important aspect of effective integration of mathematics software because teachers need to have good knowledge of when and how to bring in the relevant tools. Koehler et al. (2013) attest that CK in this context refers to the teacher's level of understanding of mathematics and how it relates to real-life situations and the ability to use correct mathematics terminology. Mr Golenyane narrated how he taught various mathematics topics in the South African high school curriculum. He mentioned that he believed that the content had to be adjusted according to the learners' abilities, and therefore he did not follow the annual teaching plan (ATP). The ATP is a teaching schedule from the DoE that aims to assist teachers with the delivery of the lesson.

*You know … in a class, you have learners who are slow and you have to go with their pace. Otherwise, they will not understand what you are teaching. We go back. Yeah, up until they understand it. And dig that concept, yeah, up until they understand it. We know that we are using the ATP but the problem is that if you go with the ATP, that is the one that is guiding us in what are you going to do this week.*

A follow-up question was posed to establish how Mr Golenyane applied this strategy in his mathematics classroom. He mentioned that if the ATP plan prescribed that he should teach factorisation in week one and then teach "find $x$" in week two, he will not move on to week two about solving for $x$ if the learners cannot factorise yet.

*Yes, you can go with an ATP, but you cannot say, for instance, from week number one you are saying you are going to do factorise, factorisation. Therefore, week two, you are going to do solve for $x$, whereas you know that these learners cannot factorise. Then you cannot jump to solve for $x$, as they cannot factorise.*

Mr Golenyane further explained that he had noted that learners struggled with the skills to identify the name of the graph and finding the x- and y-intercepts. He explained using the example of drawing the quadratic graph, and he will show learners how to determine the x- and y-intercepts by determining the value of x when y and determine the value of y when x is zero. He believed that this strategy would help to put the key points on a Cartesian plane.

> *Yah, I have noticed, most learners struggle with graphs. They don't know how do I find x-intercept when the equation is a quadratic equation for example. Then how do I find the x-intercept? They get confused. Then I tell them, let's say we have a quadratics equation, right. To the x-intercept, make y equal to zero and for y-intercept, make x equal to zero.*

It was evident that Mr Golenyane was aware of the challenges that learners experienced with studying functions. However, his explanation was abstract and posed the question to establish how he assisted learners with difficulty with functions as he acknowledged that it existed.

Mr Golenyane explained that he liked to visualise the aspects of mathematics that he taught. He often emphasises the application of concepts when he teaches a subject like geometry.

> *Uh, I think the things that are interesting and important is that learners attempt to see things by their naked eye, not imagining things. Now if you talk about the theorem, the theorem itself, you are just reading a statement.*

He further explained that when he was teaching a concept in functions on parabola graphs, the learners confused the shapes of the graphs in terms of the concave or convex shape. He referred to the parabola and how he explained the shapes of the parabola graph by linking them to happy and sad faces.

> *You know the general equation of the parabola,* $y = ax^2 + q$*. Learners, normally, they confuse the shapes of the parabola graph. So, I tell them that* $\boldsymbol{a}$ *in the equation represents the shape of the graph. Positive* $\boldsymbol{a}$ *is a happy face, so the shape of the graph faces upward because, why? It is a happy face. Again if* $\boldsymbol{a}$ *is negative, the shape of the graph is the sad face. The graph faces down … That is a sad face. This helps learners to understand the shape of the parabola graph.*

From the quotation above, it is evident that Mr Golenyane likes to help learners visualise mathematics concepts. Even though his method of happy and sad faces does not have mathematical meaning, it would help learners memorise and remember the shapes of the graphs.

#### 4.6.1.3 Integration of ICT in the teaching of mathematics

A need to equip South African schools with technology was supported by the *Guidelines for Schools: ICT Hardware Specifications* (DBE, 2012). It was essential to establish from Mr Golenyane the ICT tools to which he had access as part of teaching and learning. He told me that the school had laptops, a projector, a smart whiteboard and tablets for both the learners and the teachers.

> *At our school, we have different technology. Most teachers and myself have laptops; the school has a projector. Let me see … the Samsung people also donated tablets for teachers and learners. There is also a smart whiteboard, even though it's not working. We also have some special calculators that draw graphs.*

Mr Golenyane was despondent when he mentioned that the smartboard did not work anymore because someone had broken into the class where the smartboard was and cut the power supply connecting the smartboard.

> *It's a shame. Last Friday … They have cut the power supply to the smartboard. But I can't connect because I don't have power supply to the smartboard. They have cut the cables and the power supply.*

School vandalism and issues of safety in terms of ICT tools have been reported previously at South African schools. It was disappointing indeed to learn that such a valuable resource had been vandalised. Authorities should be concerned about the vandalism of ICT resources. Mr Golenyane mentioned that he was sad and disappointed by the act of destroying the smartboard. However, it was evident that the school had a variety of ICT tools at their disposal.

ICT has become an integral part of teaching and learning and is used for various purposes. Hence, it was imperative to establish how teachers integrated the ICT tools at their disposal in teaching mathematics. So, I asked Mr Golenyane which activities he conducted using the ICT tools that were available at his school. He mentioned that he liked to make his lessons very technological; hence he used his laptop and projector a lot. For example, he would ask learners to take pictures or videos of the lesson using the tablets. The lesson would be projected on PowerPoint, and they would take videos while he was teaching it.

> *Yeah, technology is good for communicating with learners. If I have a class, I communicate with them and they put those tablets there and they connect everything; then we have a lesson and teach. Some other times when I am in class and I say to them: "Can you take some pictures? Can you take some pictures or a video for this lesson?"*

Mr Golenyane indicated that he liked to use the smart whiteboard because it had a recording feature. He mentioned that he was able to record different lessons on the smartboard and learners could visit those lessons when they needed to.

*Then from there, we are going to record it on that smart box, then after that, if a learner does not understand that chapter, what we do is that we say go back to that smartboard and check this chapter. Check this lesson for this date, and then they go there and check the lesson. They play it again.*

Mr Golenyane further emphasised the feature of the smart whiteboard that he enjoyed using.

*And also the smartboard, it records whatever that you are doing on it. If you save the lesson, whatever you were doing there, it saves it. If you want to save it, you save it and at a later stage, you can just go there and retrieve it.*

Mr Golenyane explained how he used his laptop to enhance his teaching and learning environment. He mentioned that he used the laptop to store the mathematics software that he used in class.

*Yah, I use my laptop a lot, I can say that. I like the maths software. So, I check online and download software. It makes life easy. You just store most of the work and bring to class. I have been using some of the software since university when I was doing [my] maths degree.*

From the quotation above, it was evident that Mr Golenyane enjoyed using technology from the time he had been a student at the university.

It was essential to pose a follow-up question to establish how the teachers and learners used tablets as part of teaching and learning mathematics. Mr Golenyane mentioned that he had not used the tablets that much as an integral part of his lesson.

*Uhm for now, the tablets … we have not used them that much. I think it would be good to have a workshop. Yah, I … then we can learn how to use them for maths.*

Mr Golenyane was probed about the attitude of learners with regard to the introduction of technology in his teaching. He mentioned that there had been a general change in the learners' performance and attitude towards learning, especially in classes that were regarded as having problematic learners.

*I have seen good improvement in learners. I mean learners who were like at the bottom of the class. I see them, getting better marks so I also became serious about technology. Yes … and the learners, the class is vibrant when there is technology. Every day, when you go to class learners would be awake, they would be waiting for you to deliver the content and understand it.*

From the quotation above, there was evidence that the learners found learning with technology exciting. However, it was noteworthy that Mr Golenyane was also motivated by the learners' positive attitude to use technology in his classroom.

He further mentioned that people were living in an era where technology was easily available in the society. Consequently, learners enjoy using technology because they are constantly exposed to it and are keen on reading anything with the means of technology.

> *They know everything; even if you can just give them the computer and say: "Please read this lesson."*

Mr Golenyane revealed another challenge that had an impact on the integration of technology, namely that if something happened to teachers' laptops, they had to replace it themselves. He mentioned that his laptop had crashed and he had to solve the problem himself.

> *Hm … uhm, the laptop that I am using now, crashed and I lost everything that I had installed there. If I lose, that's it. I have to get another one myself.*

From the quotation above, it was evident that issues around the maintenance and safety of ICT tools were a challenge. Authorities should seek ways to continuously support teachers with their ICT tools, such as insurance against damage or vandalism. Once-off donations of ICT tools are not sustainable in some of the South African schooling environments.

#### 4.6.1.4 Integration of ICT software in the teaching of mathematics

With reference to the *Guidelines for Schools: ICT Hardware Specification* (DBE, 2012), which gives an indication of the specific minimum software tools that each school is supposed to have, which include, among other things, a word processor, spreadsheet and presentation software and a web browser. It was interesting to establish the practice in the integration of the various software tools to which Mr Golenyane was exposed. Mr Golenyane mentioned that he used different kinds of software to enhance the learning experience of learners in the classroom. Besides using GeoGebra, he uses Microsoft Word, Microsoft PowerPoint, CAS calculators and the Samsung School Program.

> *I started using technology in 2013. In fact, I used to use Microsoft using slides. That is the first one that I was using. Yes, I also use my PowerPoint,*

*especially in Grade 11 and 12. And we have some other calculators we were using, the computer algebra calculator.*

Even though my study is focused on GeoGebra software, it is also essential to consider other software tools available in the teaching and learning environment. Most of the software programs are interrelated, and there was an interest to know how Mr Golenyane used the software tools that he was exposed to. He mentioned that he used PowerPoint regularly for learners to watch videos that were linked to the content that he would be teaching at that time. He further mentioned that he also used PowerPoint together with GeoGebra.

*In PowerPoint, most of the time I was using videos. I was using some videos for some topics that they are not understanding. In my PowerPoint. I also use it like when I am using GeoGebra.*

A follow-up question was posed to establish exactly how Mr Golenyane used PowerPoint as part of his mathematics lesson. He mentioned that he would put geometry images and videos on his PowerPoint presentation that he would prepare for the lesson.

*For instance, geometry. Yes, then I would prepare slides therefore and also include videos in those slides, where learners would be looking at the pictures. And also, I was using pictures and also the graphs.*

I asked Mr Golenyane how he used PowerPoint with GeoGebra, and he mentioned that he used it to paste images from GeoGebra to illustrate graphs in class if he did not want to do GeoGebra live in class.

*I use it [PowerPoint] for GeoGebra when teaching functions. It is easy, sometimes. When you know you won't have time in class today, so you get the graphs from GeoGebra and paste them on PowerPoint.*

I also asked Mr Golenyane how he used the CAS software of the CAS calculator in the teaching of mathematics. He revealed that he used it regularly in the teaching of functions by using the feature in the calculator where the equation of the graph was inserted in the calculator. The calculator will then draw the graph and factorise the equation.

*Uh, in fact, if a learner is having [sic] that calculator software, the only thing that he has to do is to take a problem and put it in that calculator, for instance solve for X, we are saying they are given something like X squared minus 5X minus 6, and it's saying factorise. You just put it in the calculator and it shows you how you are going to go through the problem.*

He continued to explain how the calculator helped in teaching mathematics and stated that the calculator software helped by showing the step-by-step solution of the equation.

> *This calculator has software that is powerful. Yah, it shows you how to solve that problem step by step, starting from that, going down. It shows everything.*

Mr Golenyane continued to explain that the CAS software was an excellent tool to use, more for learners than teachers, because learners can use it for revision purposes.

> *This Computer Algebra System software was not benefiting the teacher; it was benefiting the student because after doing a lesson, then what they have to do, it has got functions and now we were talking about solving for X. You just press that function for "solve for X" and therefore it explains the steps and how they got those steps.*

He further mentioned that the learners were enjoyed using the CAS software and that there had been an improvement in their understanding of mathematics concepts using it.

> *You know ... functions are a problem. They were always happy when we were using that software. Yeah, I can say, they were understanding the concept better.*

From the quotations above, it was evident that Mr Golenyane used the CAS software to enhance teaching and learning in mathematics, even though it was for revision purposes.

Mr Golenyane elaborated on how he used the Samsung Smart School Program to enhance the teaching and learning of mathematics at his school. He mentioned that the program was connected to the tablets and formed part of teaching. The mathematics information is communicated from the Samsung program to the tablets.

> *Yes, Smart School Program. It was Samsung's Smart School Program. I have it in a video form. If I have a class, I communicate with them and they put those tablets there and they connect everything; then we have a lesson and teach. Yes, we connect it in class.*

#### 4.6.1.5 Integration of GeoGebra and the connection thereof to CAPS

The CAPS document (DBE, 2011) outlines the mathematics content areas that need to be taught in South African high schools. It encourages a learner-centred teaching practice to develop and enhance learners' reasoning and creative skills. On the other hand, my study is focused on the teachers' experiences of the integration of GeoGebra in the teaching of mathematics in South African high schools. Hence, it was essential to establish from Mr Golenyane what he thought of the link between the mathematics curriculum as according to the CAPS document (DBE, 2011) and what GeoGebra software could do. Mr Golenyane indicated that he used GeoGebra to teach concepts in geometry and functions, focusing on parabola graphs in his Grade 10 to 12 classes.

> *Yah, I use GeoGebra a lot, especially in Grade 10, 11 and 12 classes. In fact, when I am using GeoGebra, most of the time, I am using it for the chapters that are dealing with objects. Yes, like chapters in geometry.*

The CAPS document (DBE, 2011) specifies 10 subject areas that need to be taught in high school mathematics. These were discussed in detail in Chapter 2. It was therefore of value to establish from Mr Golenyane the topics that he used to teach mathematics as according to the CAPS document (DBE, 2011). He said that theorems and the parts of circles were some of the topics included in CAPS, which he also taught using GeoGebra.

> *CAPS covers lots of topics. You know, like geometry, when we are going to be dealing with theorems, for instance, like [the] angle at the centre is twice the angle at the circumference, I teach those concepts using GeoGebra.*

My study sought to explore how teachers integrated GeoGebra to teach mathematics in South African high schools. Since Mr Golenyane had previously indicated that he used GeoGebra to teach critical mathematics subject areas of geometry and algebra, mainly functions, it was necessary to establish how he used GeoGebra to teach high school mathematics content. He indicated that he liked to use it to introduce mathematics topics because he believed that this strategy allowed learners to visualise the concept that he was going to teach.

> *But first, when I introduce the topic, I use GeoGebra or the one that I was talking about, then always introduce the topic. They see the visual first and then, from there, I tell them what they have to do.*

Mr Golenyane described how he used GeoGebra to teach geometry. He explained that he drew the geometry concept using GeoGebra and illustrated the theorem by drawing circles and a triangle. The learners were then able to observe the theorem statement live and understand the logic behind the theorem.

> *Yeah, for instance theorems in geometry, we just draw the circle, put two triangles to it and then show them how the angles are changing. Why are we saying the angle at the centre is twice the angle at the circumference?*

He further explained how he used GeoGebra in teaching geometry, giving the example that the sphere has four circles and how he used GeoGebra to demonstrate that.

> *Why are they saying that? And then, by using the GeoGebra software, then you are just only to go there and pick the sphere and show them why are we saying the sphere has got four circles.*

The CAPS document (DBE, 2011) specifies that the mathematics content in high school should be taught in a manner that prepares learners for abstract mathematics at tertiary level. Hence teachers should aim to help learners to understand mathematics conceptually. Mr Golenyane explained how he used GeoGebra in teaching the measurement concept in geometry, where learners have to learn about calculating the volume of objects and that of spheres.

> *And also, for measurements, when we are talking about the volume of objects. Therefore, we are showing them why are they are saying the volume of a sphere is four over three times pi r cubed.*

GeoGebra is known to help learners visualise the abstract aspect of mathematics. Therefore, it may be vital for teachers to use where specific concepts have been taught and the teacher wants the learners to conceptualise the learnt ideas through revision. GeoGebra is recommended for use in geometry in the new Slovan and Malaysian curricula (Gunčaga et al., 2012). Mr Golenyane explained how he used GeoGebra to teach functions concepts within the South African curriculum. He explained that he used GeoGebra when he wanted to compare graphs and illustrate the increase and decrease of graphs. He would then draw different graphs using GeoGebra, with one graph showing the decreasing gradient and the other illustrating the increasing gradient.

> *Then for … also when we are comparing the graphs … why are we saying this graph is increasing, why are we saying this graph is decreasing? In GeoGebra, you can draw these graphs, then show learners that when the gradient is like this, then there is [an] increasing graph and when the gradient is like this, then there is [a] decreasing graph.*

From the discussion with Mr Golenyane, it seemed that he applied the teacher-centred approach to his teaching of mathematics using GeoGebra. There was no mention of the learners getting the opportunity to explore GeoGebra by themselves. However, it was evident that he used GeoGebra to illustrate mathematics concepts in geometry and algebra.

#### 4.6.1.6 Perceptions of teachers on GeoGebra software in the teaching of mathematics

For the purpose of the study, it was insightful to explore Mr Golenyane's perception on integrating GeoGebra in the teaching of mathematics in South African high schools. I asked him about the conception of his knowledge of GeoGebra. He mentioned that he had first heard about GeoGebra when he was still a student at university, doing his first degree, about seven years previously.

> *I started using technology in 2013. I was using it when I was still in university. That was where I heard about it and I just downloaded it, tried to use it at the laboratory of the university; then I was doing maths most of the time. Yes, and also GeoGebra, I was using it. When I started teaching, I also used it, especially in Grades 10, 11 and 12.*

From this discussion, Mr Golenyane appeared to have been exposed to GeoGebra for a long time as a student at the university and also as a teacher. That gives an indication that he has comprehensive experience in the integration of GeoGebra in the teaching and learning of mathematics.

> *Uh, I think the things that are interesting and important is [sic] that learners attempt to see things by their naked eye, not imagining things. Now if you talk about the theorem, the theorem itself, you are just reading a statement. But they would just imagine, somebody did not see that kind of things. But if you are using the GeoGebra software, you'll be seeing that what you are trying to say with that theorem. They would be seeing it with naked eyes.*

Mr Golenyane expressed his appreciation for GeoGebra software, stating that it simplified concepts and created a pleasant learning atmosphere when used as part of learning.

> *I would be saying simplicity; if you are having [sic] this software, everything is going to be simple for you. Yes. And life is going to be good, and the learners, the class, will be vibrant. Every day when you go to class, learners would be awake; they would be waiting for you to deliver the content and understand it.*

Research indicates that GeoGebra is widely appreciated because learners are able to visualise the abstract aspect of mathematics when concepts are illustrated using

GeoGebra. Mr Golenyane explained that he often advised teachers to explore the visual aspect of GeoGebra because it helped learners to understand mathematics.

> *And trying to advise them that you are not going to be behind when you are going to use this, because each and every content that you are going to use, these learners are going to understand it because they have seen what you are talking about. They didn't hear what you are saying; they have heard what you are saying and they have seen it being performed in front of them.*

Mr Golenyane further explained that he could attest to the positive contribution of integrating GeoGebra from the improved performance of his learners in mathematics.

> *GeoGebra can improve learner [performance]. When I was using [it] at another school where I used to teach, we obtained excellent results; only two learners failed from a class of 27 learners. And on [sic] that 27, we don't have level 2, starting from level 3 going up.*

Most research studies point out various challenges involved in the integration of any technology. It was, therefore, important to know whether Mr Golenyane had experienced any challenges when teaching mathematics using GeoGebra. He mentioned that one challenge was that he had taught himself how to use GeoGebra and believed that a day workshop on the integration of GeoGebra would make a difference.

> *If we can get just one day of training in GeoGebra. Just one day, maybe in like a workshop. Yah, one will be confident and we will use GeoGebra more.*

He further explained that he thought collaborating with other teachers who used GeoGebra would be helpful, as they could work together and help one another to use GeoGebra.

> *But I was telling other teachers, maybe where can meet together, where we are going to practise together, showing one another how this GeoGebra works.*

I asked Mr Golenyane where he thought he had shortcomings in terms of the integration of GeoGebra. He mentioned that he lacked confidence in using GeoGebra and that it took him too much time to prepare for a lesson that included GeoGebra.

> *Before you go to class, you have to prepare first because it's not easy to use it. Because GeoGebra needs some practice.*

He further explained that it was necessary to keep practising to teach with GeoGebra because the skill could be lost easily without practice.

> *If you can take two months not using it, you are going to have a problem because some of the functions that are being used there, you'll turn to forget. It's very important that you keep practising. Yah, time is important with GeoGebra.*

#### 4.6.1.7 PD support

There was, a need to establish the kind of PD that was available to Mr Golenyane and other teachers in the integration of GeoGebra when teaching mathematics. He mentioned that he had never received training from the DoE except for that given by the official who came to show them GeoGebra briefly.

> *For me? I can say, I never received any training of GeoGebra. The guy from the Department of Education came. He showed us briefly how we can integrate GeoGebra. I can't call that training. It was too quick. But I could follow because I knew GeoGebra.*

From the above quotation, Mr Golenyane claimed to have had exposure to GeoGebra for a substantial period, but he had received limited PD training in using GeoGebra. This is a concern because Mofokeng et al. (2010) argue that teacher PD training is the key motivational factor for teachers to integrate any form of technology into their teaching. It was, therefore, essential to establish if any follow-up training had been provided by the DoE to check how teachers were coping with GeoGebra. Mr Golenyane indicated that the official from the DoE never came again.

Although Mr Golenyane emphasised that he had received limited PD training on the integration of GeoGebra, he mentioned that there was a content workshop that he had attended where the official from the DoE used GeoGebra in his presentation.

> *No, I cannot say we did get any support, but when we are attending some workshops, in most cases, our SES they are using it. Especially when it's a content workshop. Yes, even recently, Lebo, the subject specialist, was using it. He used to use it when we attend and the last time when he was using GeoGebra was when we were attending the workshop. It was around February.*

It was interesting to learn that the subject specialist from the DoE had knowledge of GeoGebra and used it to illustrate the subject content. However, the same subject specialist did not offer the teachers adequate training on the integration of GeoGebra in the teaching of mathematics.

Despite the fact that there was minimal support in terms of PD in the integration of GeoGebra in the teaching of mathematics, Mr Golenyane indicated that they had received support with regard to technology from Samsung. The Minister of Education was with Samsung when the technological tools were received at the school.

> *Yeah, this is where I was teaching using the Samsung School, and here it was being launched and also the Minister, the Deputy Minister of Education, was here and also the ambassadors from Samsung were here. So, I was just delivering the content to the learners; this is what we are using.*

I asked Mr Golenyane to elaborate on the donation that the school had received from Samsung. He explained that Samsung had donated tablets, smartboards and the program called "Samsung School Program".

> *Yes, Smart School Program. It was Samsung's Smart School Program. Samsung was the one that was providing us with the smartboards and the tablets. Yes, they donated the smartboards.*

He further explained that the package from Samsung also came with a smart box. The learners could access the information stored on the smart box. The smart box had various content material for high school learners to access.

> *Yes, we also received the smart box. And also the smartboard, it records whatever that you are doing on it. It has high school mathematics content stored on it. Learners can access it anytime that they want to.*

A follow-up question was posed to establish how Mr Golenyane and the other teachers were using these generous donations from Samsung. Mr Golenyane mentioned that they had used the program only about three times because they lacked training in using it.

> *I always say we just need training on how to use technology because [the] days of paper are gone. Even learners know technology more that teachers. Even with Samsung technology, we're just not sure sometimes.*

He further mentioned that sometimes they wanted to use tablets, but they did not have enough for each learner and therefore it did not work well in class.

> *Some other times when I am in class and I say to them: "Take pictures or get to this software." But now they will be sharing because the tablets are not enough for each learner. The class becomes chaos. Then you end up thinking, maybe I should not be using these tablets because now; you will lose time.*

From the discussion with Mr Golenyane, it was evident that the schools had received many ICT tools from private entities such as Samsung, which were endorsed by the Minister of Education. However, there appears to be minimal training and support for teachers in terms of how they can use these resources to improve the teaching of mathematics.

#### 4.6.2 Lesson presentation – Mr Golenyane

The data below have been derived from the non-participatory observation of Mr Golenyane's mathematics class teaching with GeoGebra. Particular attention was paid to the mathematics content, his teaching practice and, most importantly, how he integrated GeoGebra in teaching the chosen mathematics topic.

##### 4.6.2.1 Introduction

The lesson observation taught by Mr Golenyane started with a pre-observation interview to gain an understanding of the mathematics content to be taught, the ICT tools relating to GeoGebra that he had prepared to use, the expected prior knowledge of the learners and any misconceptions on the taught content.

During the pre-observation interview, Mr Golenyane indicated that he would be teaching functions on straight lines and parabola to Grade 11 learners. When asked about the learners' prior knowledge, he mentioned that he expected the learners to know about linear graphs because that aspect of functions is covered in Grade 9 and 10. He, however, expected that they would have misconceptions with regard to identifying the name of the graph, finding the x- and y-intercepts, reflection and rotation in different quadrants of the Cartesian plane. He further explained that from this knowledge on functions, the learners would build a foundation of understanding trigonometric graphs. I asked Mr Golenyane about the ICT tools that he was going to use with GeoGebra in his lesson, and he mentioned that he was going to use the projector, laptop and whiteboard.

##### 4.6.2.2 Teachers' practices in the teaching of mathematics using GeoGebra

Mr Golenyane presented a lesson to Grade 11 learners on the functions topic. He told the learners that GeoGebra would help them visualise some aspects of the content that they would be covering in class. He told the learners to take out their textbooks and then told them that they were going to discuss different types of functions, starting with linear functions, and later they would learn about parabola. He then asked the learners if they knew what a linear graph was. One learner answered: “Straight line.” Mr Golenyane was trying to engage with the learners by asking different views of what a linear function was. The lesson covered Grade 10 mathematics as specified in the CAPS document (DBE, 2011). Firstly, functions is a mathematics topic covered in the FET curriculum. Secondly, the scope of work that is covered under functions for Grade 10 includes linear and some quadratic polynomial functions. Learners are also encouraged to know different kinds of graphs (DBE, 2011). Hence, the introduction of the lesson during the observation was within the content as referred to in the CAPS document.

Mr Golenyane started the lesson by writing the general linear equation on the board. He told the learners that the linear equation could be represented as follows:

$y = mx + q$. He explained that m represented the gradient and that q represented the intercept. Furthermore, it was important to consider the effect of the gradient and the intercept. In order to engage the learners, he asked them to give any equation of the straight line. The first learner gave an equation $y = 2x + 1$. From the equation, the learners had to state what the value of the gradient and intercept was. The answers given by the learners were correct. The learners appeared to be engaged and curious, especially when one of the learners asked Mr Golenyane what would occur if there was no intercept. He drew the graph as reflected below. ***Figure 4.8*** below illustrates $y = 2x + 1$ when 1 is the y-intercept and $y = 2x$ and there is no y-intercept.

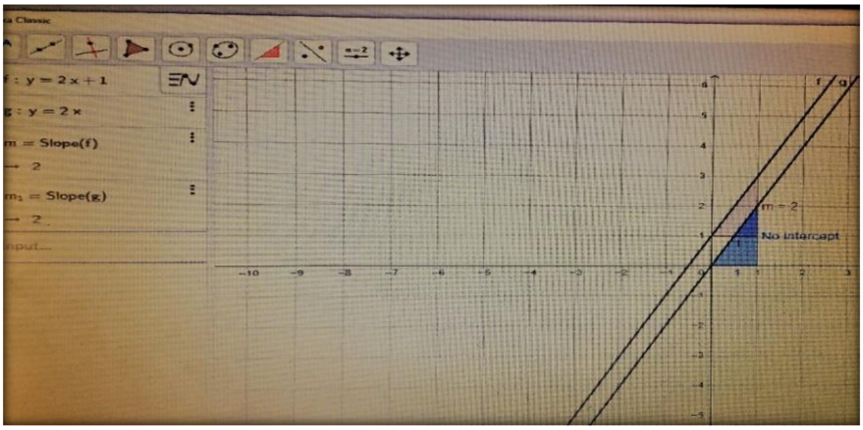


**Figure 4.8: Picture for the illustration of linear functions during Mr Golenyane’s non-participatory class observation**

The lesson continued with Mr Golenyane introducing a variation to the equation by introducing a negative y-intercept. He wrote the equation $y = 2x - 1$ on the board. There were deliberations about $(-1)$. He further introduced an equation where the gradient was negative: $y = -2x - 1$. He told the learners that the gradient was a measure of how steep or gentle the slope was. He illustrated the comparison of the equations using GeoGebra. ***Figure 4.9*** below presents the illustration on GeoGebra.

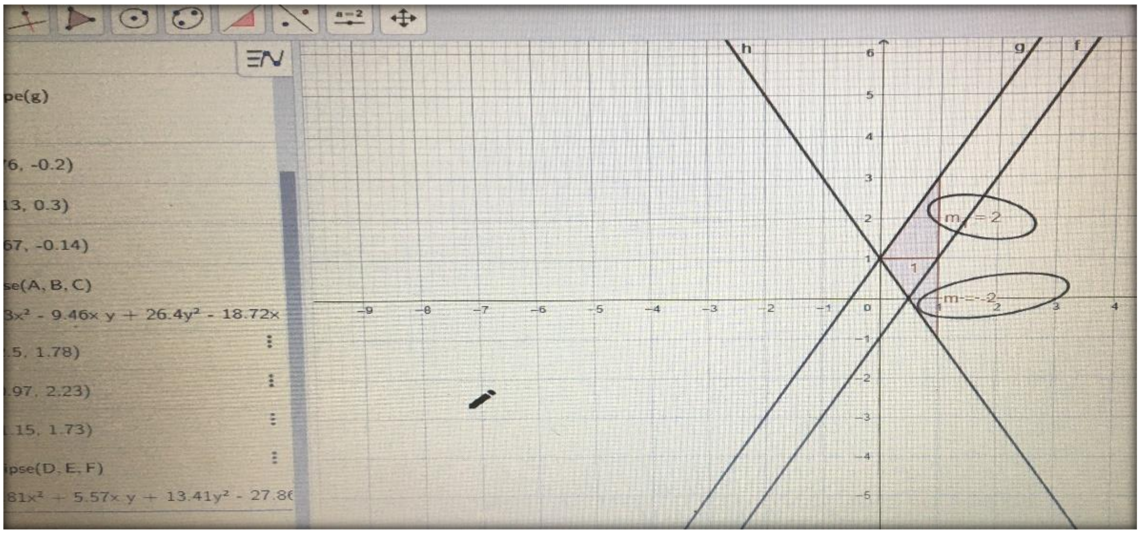

**Figure 4.9: Picture taken to illustrate the negative and positive gradient during Mr Golenyane's non-participatory class observation**

From ***Figure 4.9*** above, it was clear that Mr Golenyane was familiar with the content topic. He pointed out the change in slope with the change in the y-intercept. He then integrated GeoGebra to demonstrate the linear graph to the learners.

Mr Golenyane inserted the linear equation $y = 2x - 1$ as input in GeoGebra. From the equation, he told the learners that 2 represented the gradient or the steepness of the graph and -1 represented the point where the graph cut the y-axis. He then inserted the equation as input in GeoGebra. The illustration of the GeoGebra graph is shown below (***Figure 4.9***).

There was some excitement in the classroom and the learners were curious to know what would happen when some values of the gradient changed. One learner asked Mr Golenyane what would happen with the equation if the gradient was bigger than 2.

Mr Golenyane inserted the equation $y = 8x - 2$ ; $y = 6x$ and $y = 12x$. ***Figure 4.10*** below shows what happens when the gradient changes.

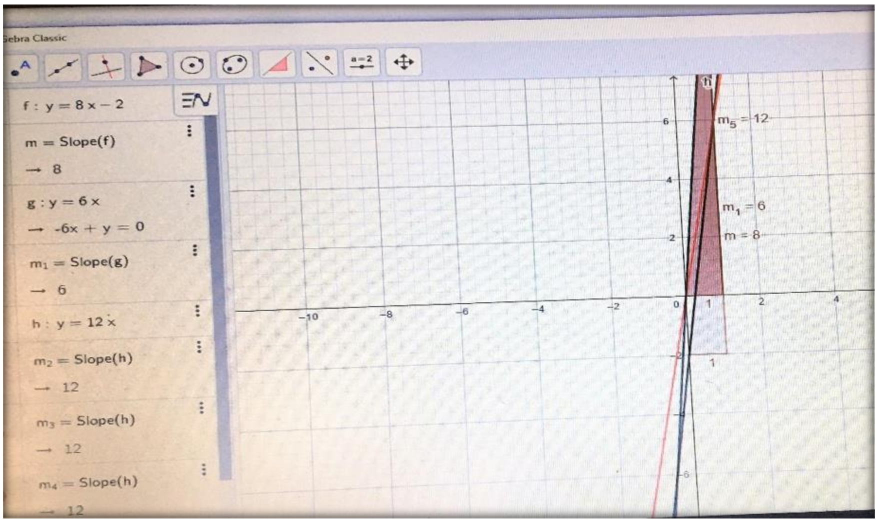


**Figure 4.10: Picture taken to illustrate the change in gradient linked to the value of the gradient**

Mr Golenyane introduced the parabola graphs by first telling learners about the general equation $y = Ax^2 + Bx + C$. He told the learners that A represented the shape of the parabola graph. If A is positive, there is a happy face graph and if A is negative, there is a sad face graph (see ***Figure 4.11*** below). He then introduced an equation with values and inserted the same equation into GeoGebra.

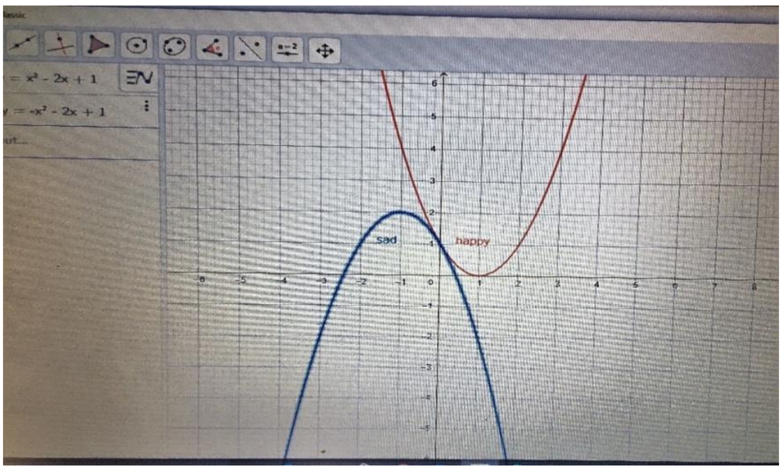


**Figure 4.11: Picture of a parabola graph representing the coefficient of the $x^2$**

Mr Golenyane further explained that from the same general equation $y = Ax^2 + Bx + C$, B represented the movement of the graph horizontally, which is the movement of the graph along the x-axis. He then told the learners about the C and that it represented the movement of the graph vertically, which is either up or down. ***Figure 4.12*** displays C, movement.

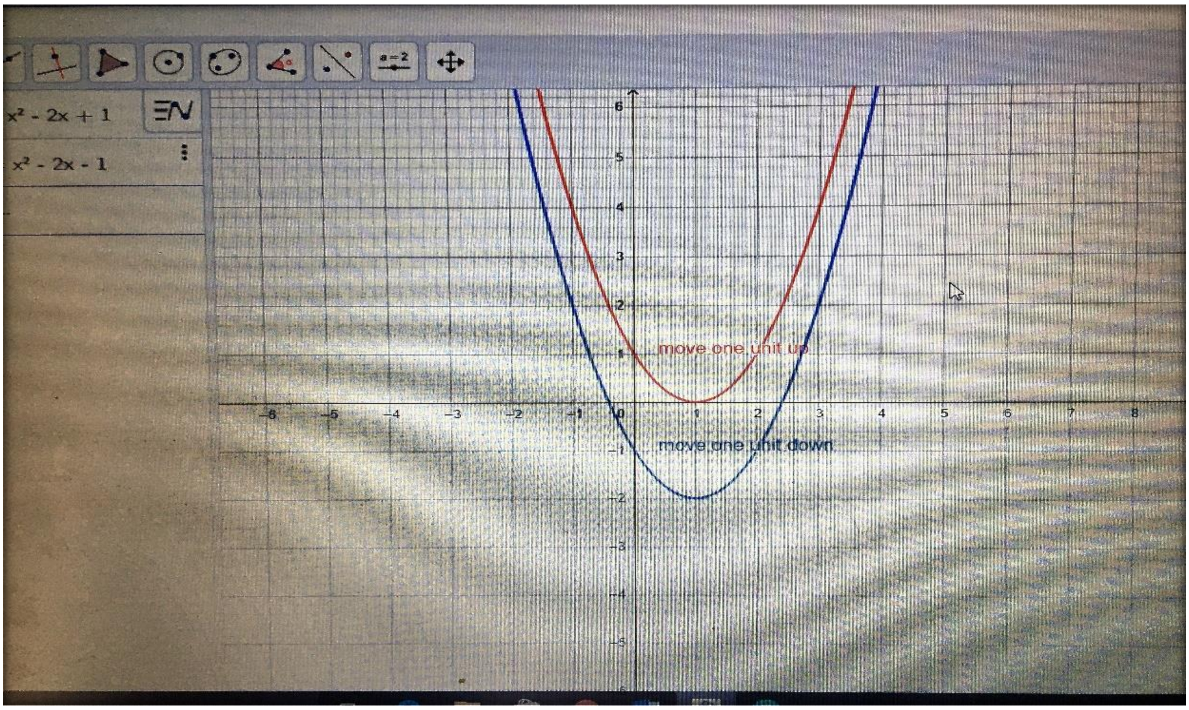


**Figure 4.12: Representation of the movement of a parabola graph along the x-axis**

### 4.6.2.3 Instructional practices or strategies

#### a) Teaching strategy

According to Meng (2013), GeoGebra is a mathematics software tool that enhances the teaching of algebra and the visualisation skills of learners. It was therefore insightful to be in Mr Golenyane's class to witness how the learners were engaged during the lesson. GeoGebra seemed to enhance the learners' curiosity as demonstrated by their questions when Mr Golenyane was teaching. They asked about the possibilities of a change in the gradient and what the effect of the change would be on the graph. During the semi-structured interviews, Mr Golenyane indicated that he liked to employ a learner-centred teaching strategy where learners were encouraged to think and create their own meaning. It was evident from the observed lesson that Mr Golenyane was trying his best to engage the learners. The lesson would, however, have been more interesting if the learners could have had access to GeoGebra themselves.

**b) Management of assessment**

There was continuous engagement between Mr Golenyane and the learners. Towards the end of the lesson, Mr Golenyane told the learners to take out their textbooks for the classwork assessment. In the assessment, the learners were requested to estimate the graph by analysing the equation. The time was limited and Mr Golenyane instructed the teachers to finish during their free time and they would check it together the next day. During the post-observation interview, Mr Golenyane indicated that it would have been good if the learners could have done that part of the assessment on GeoGebra. However, it could not be done as the school mathematics laboratory did not have computers.

#### 4.6.2.4 Teachers' challenges in the integration of GeoGebra in the teaching of mathematics

During the semi-structured interview, Mr Golenyane indicated that he was familiar with GeoGebra, especially the integration of GeoGebra in mathematics lessons. However, during the observed mathematics lesson, Mr Golenyane did not explore most of the features of GeoGebra when teaching functions. He was very hesitant in drawing the parabolic functions on GeoGebra. He drew a new graph every time he wanted to illustrate the change in the gradient, although it would have been interesting to draw all the graphs in one Cartesian plane. However, his limitations in using GeoGebra effectively were due to the lack of professional training in using GeoGebra. He displayed a positive attitude and expressed that he believed that GeoGebra could enhance the learning experience of learners. He was not impressed that the lesson did not integrate GeoGebra as much as he wanted. He reiterated his frustration about the lack of training expressed in the semi-structured interviews.

> *We received very little training in using GeoGebra. If we can have more training … Ya, we could use GeoGebra more in class. The training happened in the principal's office. We were just given the manual and the gentleman showed us a little how to use it.*

## 4.7 Case 4 – Mr Maziya

### 4.7.1 Interviews – Mr Maziya

#### 4.7.1.1 Background

Mr Maziya has been teaching at his present school for the past five years. He has a BEd degree in Science and Mathematics, a BEd (Hons) degree in Physical Science and is currently working on his MEd degree. He mentioned that he found mathematics too easy; hence he has chosen to do research in science, focusing on the application of mathematics in science. His teaching experience includes teaching mathematics to Grades 8, 9 and 10 and teaching science to Grades 11 and 12. Mr Maziya has also been approached by a school in a nearby city to give extra classes to Grade 12 in mathematics and science. Therefore, Mr Maziya's current teaching experience extends beyond his current school where he is employed full-time. Mr Maziya demonstrates a keen interest in mathematics as a subject and good skills in teaching. He has a wealth of experience as a mathematics teacher and a researcher in the field of mathematics and science.

> *Okay, currently, I have a BSc Honours and I am doing [a] master's in Education. I did my BEd, both Maths and Science, but in my Honours, I did Physical Science. Ah … I find maths too easy. So, I just do science. You see, science is about the application of maths. Even in my master's, I do science because I see science is about the application of maths. Teaching? I have been teaching here [current school] … This year is the fifth year. Let me see ...Yah! Four years and eight months. Teaching Grade 9 maths … I am teaching now for 5 years. But Grade 10, I taught for about two years. But you know … I also teach maths and science at a school in Rustenburg. The principal there asked me to come teach their Grade 12 learners.*

It is evident that Mr Maziya boasts of wide experience in the teaching of mathematics and science, and his exposure to research through his master's degree in Education has shaped him to be a valuable teacher in the field of mathematics and science.

Mr Maziya further mentioned that he has been promoted to being the head of the department of mathematics at his current school. That promotion places him at the school management level and he is now responsible for all issues related to mathematics at his school.

> *I have been at this school, since I started working … It would be about five years.*

*Yes, also, I am the HoD [head of department] for maths. The appointment came as a surprise. But I am happy.*

When I asked him about his experience of teaching mathematics at his current school, Mr Maziya said it was pleasant and interesting. However, he felt that the learners' performance was not impressive. He mentioned that some of the learners had responsibilities of being parents themselves – some had single parents and some had parents who worked long hours at the local mines. He was of the view that those challenges had an impact on how the learners felt about learning and that affected their learning in general and mathematics performance in particular. Okafor et al. (2013) agree with that observation as they state that a negative home environment has a negative impact on learners' performance.

*You know, Ma'am, at this school, most learners do not have parents. There are child-headed families Sometimes you ask the learner why they did not come to school. They will tell you straight: "My mother did not come home or she is not there and I have to take care of my siblings, one or two." Fathers are not there or work long hours at the mine.*

From the above quotation, it was evident that the general home environment situation in the school district was negatively affecting teaching and learning at the school.

Mr Maziya also mentioned that the school was in a community that posed a threat towards education at his school because there had been a burglary at the school in which the computers had been stolen. He believed that the loss of those computers was a reflection of the lack of support from the community. Consequently, the lack of support is also reflected in the learners' lack of interest in education, especially in mathematics.

*You know, Ma'am, all computers were stolen from this school. But no one was arrested. This school is so close to the community. You want to tell me that no one saw anything. They started by stealing the fence around the school. Imagine, the fence! Then [the] computers were stolen. All of them. I live in the school yard. You know, when I leave, I have to take everything out. One time, they stole my TV and stuff.*

Mr Maziya's account of the theft of property at the school posed a concern. It painted a picture of a community environment that was not supportive, hence negatively affecting teaching and learning at the school.

Mr Maziya continued to express challenges that he believed were affecting the performance of learners in mathematics. He associated the poor performance in mathematics to the learners perceiving mathematics as difficult and abstract. This view is confirmed by Even et al. (2013), who also found that learners feel that mathematics involves concepts that are abstract and difficult to understand. This observation from Mr Maziya is worth noting because he has been a teacher for five years at the school and has been the head of the mathematics department for over a year. His view stems from his teaching experience at his current school as well as the school he supports on Saturdays. Mr Maziya is constantly looking into the mathematics performance at the school both as a teacher and holistically as an administrator in the teaching and learning of mathematics.

> *Yeah, okay, I think teaching maths is nice and the same time is … it's actually … what can I say? It is interesting, though it teaches you how learners learn, how learners see maths as an abstract subject because in my experience, learners find mathematics challenging.*

He further expressed concerns about the learners' attitude towards mathematics and towards learning in general.

The poor performance at Mr Maziya's school was clearly a matter of concern for him. He continued to talk about other factors contributing to the learners' poor performance in mathematics. Mr Maziya believed that the poor performance in mathematics was linked to the fact that, in general, the learners at his school did not do their homework. Guostafsson (2012) agrees with this view as he found that countries that performed better in mathematics were countries that engaged in quality homework as part of assessment, which is crucial for teaching and learning. Homework is that part of assessment that allows learners to practise mathematics. This allows both the learner and the teacher to learn those aspects of mathematics that were not understood. Homework also allows repetition, which is crucial for remembering mathematical facts and learning in general.

> *I guess because it [mathematics] needs daily practice and they are lazy; they don't give it time because maths needs time. It's an everyday language; it needs daily practice as you give them exercises every day, homework every day, and you find that most of that homework, they don't do them. So, I think maybe they have a lot of work, I guess because they are not only doing mathematics, there are other subjects, it's nine subjects*

*and they have to cope with all that. So, they don't practise maths every day … maths needs to be practised every day, and I think that is why they find maths difficult.*

Mr Maziya stated that he believed that mathematics was the kind of a subject that needed constant practice and he was of the opinion that that could be the major contributing factor towards learners finding mathematics concepts difficult to understand. A follow-up question was posed about the reasons for learners not doing their homework. Mr Maziya had this to say:

*Sometimes learners don't do their homework because they spent too much time on WhatsApp chatting to their friends. I have heard some parents complain about that. Sometimes, they [learners] try to do their homework and they will tell you … I tried but I have given up ... I could not do it … I didn't know what I was supposed to do.*

Mr Maziya believed that other than the abstract nature of mathematics, learners' attitude and surrounding social factors were contributing reasons for their lack of interest and poor performance in mathematics.

#### 4.7.1.2 Mathematics CK and pedagogical knowledge

The integration of mathematics software in the teaching and learning of mathematics demands that the teacher possesses a good knowledge of mathematics and has the necessary skills to teach. This study is focused on how teachers integrate GeoGebra software in their teaching of mathematics. The integration of GeoGebra as a mathematics tool requires both knowledge of mathematics and pedagogical knowledge of teaching mathematics. Even et al. (2018) hold the view that the understanding of mathematics is measured by the correct use of mathematical language and symbols, the ability to relate mathematics concepts and being able to address critical parts of the concept. I asked Mr Maziya to narrate how he taught various mathematics topics in the South African curriculum to establish his knowledge of mathematics and his ability to teach it. Explaining how he taught the Grade 9 number system, he said:

*Alright, yeah uhm, ok, let me say that especially on the Grade 9 level for them, the Grade 9, we do a lot of number system. Counting, so number system is counting, and they count every day. When you count, neh, one learner asked me: "Okay, Sir, why do you say these are natural numbers?" And I said: "Okay, let's make a practical example. You go to a shop and then I say go and buy me sweets, five sweets. And it is natural for you to start counting from one and count. You don't say: 'I want 1.0 sweets and*

*2.0 sweets.' So, the natural way of counting, we are using 1, 2, 3, 4, 5. Then that is why we are saying natural numbers start counting from one, not zero and that is why we do not include zero. Because that is naturally so you count from one, and that is how we got to that classification that these are natural numbers." Yeah, that is where now we use application versus understanding.*

From the quotation above, Mr Maziya gave an example of teaching Grade 9 the number system as a mathematics concept. He referred to natural numbers and the reason for the mathematical language behind the term "natural numbers". He described how natural numbers differed from integers and the application thereof in real-life situations, using the correct terminology and how it related to real-life situations. Due to the nature of my study, which seeks to understand teachers' knowledge of mathematics, I sought to understand how Mr Maziya's actually integrated GeoGebra in his teaching of mathematics.

It was also important to understand Mr Maziya's skill in teaching mathematics within the context of the study. Mishra et al. (2006) talk about pedagogical knowledge as evidence when teachers can build on their learners' prior knowledge and adapt their teaching strategies to best facilitate new content to teach the learners. Mr Maziya noted that sometimes learners confused the integers on a Cartesian plane and that numbers decreased as one moved to the left when dealing with negative numbers. Also confusing to the learners is the fact that -1 is bigger than -2.

*And sometimes you find that they confuse the left with the nature of the numbers; left is negative and why you say left is negative.*

*That convention, so they would see that when there is negative 1 and negative 2, so the left means it's towards the direction of the negative numbers.*

Mr Maziya was probed to give another example of how he taught mathematics at his school. He mentioned teaching a concept in geometry about theorems, for example theorems that apply to circles talking about the inscribed angle (the angle made from points sitting on the circle's circumference). From that theorem comes a theorem called "the angle at the centre theorem", which states that the angle at the circumference is twice the angle at the centre. However, Maziya confused the theorem a little when he confused the angle at the centre and at the circumference. He did, however, understand the theorem and its application.

*Yeah ... I teach not only graphs but even circles. Okay, for example … if I want them to apply theorems. Okay, let say, you want to show them how theorems apply, but first you draw the circle or show them a drawn circle with the lines forming the angles at the circumference. Right … Then you talk about [the] inscribed angle. Okay … The same lines also connecting to form the angle at the circumference of the triangle. Okay, then you tell them about the relationship of the angle at the centre and the angle at circumference. You know, the angle at the centre is twice the angle at the circumference.*

Mr Maziya had mentioned before that he also taught graphs. Follow-up was done to establish how he taught graphs. He mentioned that he would teach a concept of functions where, for example, he would explain to the learners how to draw a graph, for instance $y = x^2 + 1$.

*Okay, I want, for example, to ...okay, I want to show my learners how to draw a graph x squared plus one. Right, then I would show them that when you draw a graph, you must have a set of ordered pair. Yes, and this is how we plot. We always use a zero as our reference point; let's say the coordinate is negative then you get y equals to two. But for the learners that one is difficult, though it sounds easy though. So, I would show them that you move two steps to the left … something like that.*

Mr Maziya gave an interesting example illustrating a method to draw a graph. But his examples were difficult to understand from his explanation and he mentioned that he used technology a lot to help him illustrate such difficult concepts to learners.

#### 4.7.1.3 Integration of ICT in the teaching mathematics

In this study, I sought to establish the ICT tools that Mr Maziya was exposed to and how long he had used ICT in his teaching of mathematics. Mr Maziya has been using ICT since he started teaching five years previously. He regularly uses various ICT tools for general social activities and general administrative purposes. He mentioned that he often used a projector, his laptop and his smartphone for teaching and for administrative purposes. It was evident that Mr Maziya used various ICT tools and had been using them for years. That would make him experienced in using ICT tools.

*You mean ICT tools, neh? I have been using my laptop for a long time ... I'm regularly on social media ... WhatsApp. So as soon as I started teaching, I would say that 80% of my time is projector [sic]. Yes! I use the projector, so I would say I started using technology as soon as I started teaching. I also use my laptop for communication, like sending email. I also set question papers. The question papers for exams and tests, I use my laptop to type the questions papers.*

Mr Maziya also mentioned that his school had been provided with tablets to use as part of teaching and learning. The tablets were part of the project that he referred to as “CAP”. The CAP programme has tablets that are connected to specific websites. The CAP programme also has textbooks and past question papers in Grades 10, 11 and 12 for most subjects, including mathematics.

> *Yeah, he brought something called a CAP, C.A.P., whereby learners can log in. It only leads them to certain websites where there’s textbooks, past papers for Grade 10, 11, and 12. Yeah, almost all subjects are there, it is a wi-fi but for only that website. We were given tablets with this CAP. We give learners tablets and they log in and then they get past papers and some textbooks online from that website.*

From the above quotation, there is an indication from Mr Maziya that he uses various technological tools to enhance the learning environment. He confirmed that the CAP programme was user-friendly and learners enjoyed using it.

Mr Maziya acknowledged that using tablets during teaching time had a positive impact on the learning environment. I asked him whether the learners were engaged during teaching time when tablets were used.

> *They are! Exactly, they are very engaged. Okay, because learners like technology and they enjoy a class when you use a projector and other means of software, they enjoy seeing that part.*

Follow-up was done to establish how Mr Maziya used the projector in teaching mathematics. He mentioned that he actually used the whiteboard instead of the normal blackboard as part of his everyday teaching. Thus he used the projector all the time as part of teaching.

> *You mean ICT tools, neh? I use it every day as part of my teaching. I would say that 80% of my time is projector. I don’t use the blackboard in my class. I use the whiteboard. So, I put everything on my laptop and use the projector.*

When probed what sort of mathematics content he would put on his laptop to project in class, Mr Maziya said:

> *You know … I can say, I love my computer. Normally, neh, I put the information say on PowerPoint and then when I come to class, I just put [it on] the projector. My learners know. Sometimes, I want them to watch a video on a mathematics lesson. Maybe it’s a difficult concept. Yoo ... especially those difficult theorems in geometry.*

Mr Maziya further mentioned that he used the projector when he assessed the learners in class. He believed that the projector allowed him to save teaching time.

> *Most of the time, I use the projector because it simplifies things and saves time. Even when you give learners classwork, you don't have to write everything on the board. You just project the work. The time you will normally spend writing on the board, you can be engaging with learners.*

Mr Maziya indicated that he enjoyed using the laptop and that is saved time. He could not imagine life without the various ICT tools. At his school, teachers set question papers and then printed these. In addition, he used it for his academic research work.

> *You know in my office, at the back, I keep most of the technology. I told you "mos" I am doing my master's. I have to use my laptop for my research work. I also use it, like when we set question papers.*

Mr Maziya continued to talk about the various ICT tools that he used in teaching mathematics. He said he used a smartphone for the WhatsApp group for the class that he taught. He felt that it was effective because learners who owned smartphones were constantly using them, among other things, to reach out for assistance in cases where a WhatsApp group existed.

> *As young teachers in the technological era, the usage of technology is part of what happens every day. Like in my class, I have a WhatsApp group where I send work to do. Learners use this platform to ask questions when they are not sure.*

Mr Maziya further mentioned that the use of smartphones also held challenges. He had observed that some learners could not afford smartphones. Some learners who had smartphones did not have access to the Internet or wi-fi because they could not afford data.

> *But I realised that some learners do not have smartphones. Maybe sometimes, they do not have data. So, sometimes it works, sometimes it doesn't.*

It is thus clear that using smartphones as part of learning has advantages as well as disadvantages. While they provide a platform for learners to continue to engage with their teacher and peers outside the school environment for learning purposes, smartphones have the disadvantage that some learners cannot afford them and, thus, may be excluded from learning.

Mr Maziya indicated that his school used to have a mathematics laboratory and a whiteboard. However, the computers from the mathematics laboratory had been stolen.

> *Yoo … the school used to have the computer lab, which is now used as a classroom. There were about 20 or 30 desktop computers. One day, we arrived and all the computers were gone. Now, learners do not have computers to work. The computer lab is now a classroom.*

It was evident that the theft of the computers from the computer laboratory had been a huge loss. I asked Mr Maziya how the computers had been used as part of learning. He mentioned that he used to have mathematics lessons at the laboratory where the learners could also explore the technology for themselves. In addition, teachers could give projects that required learners to work on computers as groups or individuals.

> *Eish! It used to be good when there were computers … Learners love to work with technology. They will be so excited when you say: "Today we are working at the lab." I would give them maybe classwork ... Let's say we did a maths lesson in class. Yah … next time we will go to the lab and do the maths we did in class.*

Most of the research done on South African teachers' integration of ICT tools in their teaching has found that the attitude of teachers was a hindrance to the integration of technology into teaching. Baya'a et al. (2013) are of the view that teachers' attitude towards ICT and their confidence in ICT use are among the factors that influence the integration of ICT in the classroom. Thus, follow-up was done to establish how Mr Maziya felt about using ICT tools.

> *Okay, I like it [using ICT tools] really. Most of the time, I use the projector because it simplifies things and time. I mean I use my laptop all the time to prepare the lessons. Yah … What can I say? I love technology. I use my cell phone all the time. Technology is good. Learners get excited, just when they see it.*

#### 4.7.1.4 Integration of ICT software in the teaching of mathematics

In my study, there was an interest in establishing how Mr Maziya was using various software tools that he was exposed to in the teaching of mathematics From the discussion above with Mr Maziya, it was established that he had been exposed to various ICT tools. Therefore it was necessary to establish the various ICT software tools that he had been exposed to in teaching mathematics. Mr Maziya said that he used multiple software tools for various purposes. Besides using GeoGebra, he uses Microsoft Word, PowerPoint and other software tools that come standard with tablets.

*Okay, I would, okay … I use different software. I mean like I said, I use my computer a lot. I use Word most of the time. Then PowerPoint, almost for all my lessons. And you know, when we had [the] CAP programme, like when we had it in the tablets. I use them for different reasons.*

I posed a follow-up question to establish how Mr Maziya used the various software programs in teaching mathematics, starting with PowerPoint. He replied that he used PowerPoint a lot for presenting lessons, as he did not have a blackboard in his class.

*Hmm, software, let me see … I use PowerPoint every day for teaching. My class does not have the [sic] blackboard. Therefore, I use the textbook and PowerPoint. All my lessons are prepared on PowerPoint.*

He continued that he used Microsoft Word to enhance his teaching environment. He indicated that he used Word mainly for typing question papers. Sometimes he used it to present classwork for learners as an alternative to questions from the textbook.

*And yes, when we set question papers, I use Word to type question papers. We type question papers ourselves. And also, when we record learners' marks, it is easy to use Excel. Sometimes, the textbook does not have good exercises for classwork. So, I get my own questions and type them on Word to present in class.*

As Mr Maziya mentioned that he used Excel as part of teaching, I examined how he used Microsoft as part of his teaching, with the knowledge that there was so much that could be done in teaching mathematics with Excel. Mr Maziya mentioned that he only used Excel for administrative purposes, which entailed recording his learners' marks and getting records of assessment results, as the head of department for mathematics at his school.

In addition, follow-up was done to establish how Mr Maziya conducted his mathematics lesson using PowerPoint. He indicated that he copied some of the illustrations that he got on Google. He typed the lesson objectives, examples and classwork activities for lessons. Mr Maziya had a lot of confidence in the use of PowerPoint. It was clear that it was a good substitute for the normal board in class for him.

*Okay, let me see … I normally get like some examples of my work on Google. If I get something interesting and maybe relevant to my lesson, I then copy and paste it on PowerPoint. I type the lessons examples and maybe [the] page number of the classwork and learners can open that page when it is lesson time. Yah, PowerPoint makes my life easy.*

*Yeah, he brought something called a CAP, C.A.P., whereby learners can log in. It only leads them to certain websites where there's textbooks, past papers for Grade 10, 11, and 12. Yeah, almost all subjects are there; it is a wi-fi, but for only that website. We give you tablets with this CAP; we give learners tablets and they log in and then they get past papers and some textbooks online from that website.*

Studies show that teachers are not always keen to do research on the mathematics topics that they teach. It was therefore important to establish whether Mr Maziya was aware of any software that was valuable in teaching mathematics. It was evident that Mr Maziya was aware of various software programs that were valuable for administration purposes. He had not made time to investigate other important mathematics software that could enhance the learning experience of his learners. Mr Maziya indicated that a lack of time was a hindrance to expanding his knowledge on the various available software to enhance the learning experience of his learners.

*You know, Ma'am, there is actually no time to do a lot of research. We have to focus on finishing the curriculum as prescribed in the annual teaching plan. But at least, now we know about GeoGebra*

From the above quotation it was evident that Mr Maziya was exposed to various ICT software programs but had not gained enough knowledge about these, other than GeoGebra.

#### 4.7.1.5 Integration of GeoGebra and the connection thereof to CAPS

It was important to establish from Mr Maziya what he thought of the link between the mathematics curriculum, as according to the CAPS document (DBE, 2011) and what GeoGebra could do. Mr Maziya mentioned that it would be a good idea to integrate GeoGebra as part of the high school curriculum and include it in CAPS. He believed that most of the mathematics content in the CAPS could be illustrated using GeoGebra.

*It would be great. That would be great to have GeoGebra in CAPS. Let me say, I would love it if it would be implemented in CAPS and be a part of it, because it helps a lot with teaching concepts. I think it helps teach concepts better and, definitely, I think I would recommend that it is integrated in CAPS.*

Mr Maziya gave examples of the correlation between CAPS and GeoGebra and stated that CAPS required that when graphs are taught to Grade 9 learners, they should know how to draw the graphs. GeoGebra is pivotal in drawing those kinds of graphs.

> *Yeah, they do, they do match, CAPS and GeoGebra because, if for example, I am using GeoGebra to teach geometry at Grade 9 for example, or graphs, or and then CAPS, yes, CAPS would be saying learners have to be taught how to draw graphs. Meaning that automatically, if GeoGebra allows me to draw a graph on the graph slope, then definitely we rely [sic]. Yeah, because it supports what CAPS wants us to do.*

GeoGebra could be used to teach a variety of mathematics topics, and Mr Maziya indicated from the quotation above that there was a strong link between GeoGebra and the curriculum as specified in the CAPS. It would, therefore, be insightful to establish which mathematics concepts included in the CAPS he taught using GeoGebra and how he taught those topics using GeoGebra. Mr Maziya mentioned that he used GeoGebra to teach a variety of graphs, including straight-line graphs, number patterns and geometry of two-dimensional shapes.

> *And, yeah, you can teach a number of topics using GeoGebra. Like geometry of straight lines, graphs, number pattern, counting, uh, geometry of 2D shapes. Yah! There is a lot; it's just that I can't remember others.*

I asked Mr Maziya to give an example of how he would teach geometry using GeoGebra. He replied that he used GeoGebra to teach geometry when he taught the angles in the circles and the sum of the angles of the triangle.

> *I mainly use it in … including geometry and for mathematics, uh, to show them the angles inside the circle subtended by the cords and the arc. Sum of the angles of the triangle. You know, [the] sum of [the] angles of a triangle are [sic] equal to 180 degrees,*

I asked Mr Maziya to elaborate by giving specific examples of how he used GeoGebra to teach the angles in a circle and the sum of the angles of a triangle. He explained that he would illustrate the sum of the angles of a triangle remained 180 degrees regardless of the size of the triangle. So, he would start by drawing a small triangle using GeoGebra and then keep increasing the size of the triangle. The learners would be fascinated to see that the triangles always stay the same.

> *Okay, let's say, I'm teaching learners about the sum of the interior angles of a triangle. You know the sum does not change … it doesn't matter, the size of a triangle. So, I would draw a triangle on GeoGebra. Okay … GeoGebra allows you to draw, expand the triangle or you can make it small if you want. Yah … Learners will be fascinated to see it live, that the*

*sum of [the] interior angles of [a] triangle are [sic] equal to 180 degrees for real.*

GeoGebra is regarded as a good tool to use when teaching functions in mathematics because of the accuracy of the graphs and that it can be used to illustrate the mathematics concepts live to learners. Mr Maziya mentioned that he used GeoGebra to teach a variety of graphs. I posed a follow-up question to establish how he taught graphs using GeoGebra. He explained that he had realised that the learners confused the graph labels, especially the negative numbers; therefore he used GeoGebra to clear that confusion.

*And sometimes you find that they confuse the left with the nature of the numbers, left is negative and why you say left is negative. To clear that confusion, I use GeoGebra, so they would see that when there is negative 1 and negative 2, so the left means it's towards the direction of the negative numbers.*

Mr Maziya further explained that on the topic of functions, he preferred GeoGebra because it gave a Cartesian plane with grid lines. He projects the grid to illustrate the movement of the graphs.

*So, I can show on the grid that the sketch that I am talking about, I am talking about these intervals on the grid and I would count "1, 2" and they see. Then I would count maybe two steps upwards, "block 1, block 2" and then it's here.*

From the discussion with Mr Maziya, it was evident that he used GeoGebra in some aspects of teaching mathematics. It was also evident that his limited exposure to and knowledge of GeoGebra hindered his skill in using GeoGebra.

#### 4.7.1.6 Perceptions of teachers on GeoGebra software in the teaching of mathematics

For the purposes of the study, it was interesting to explore Mr Maziya's perceptions on integrating GeoGebra in teaching mathematics in a South African high school. I asked him about his knowledge of GeoGebra. Mr Maziya said that he had first heard about GeoGebra two years before and he had been using it occasionally in his mathematics lessons.

*Ahh! GeoGebra? Let me see. I first heard about it in a PSF [professional development workshop]. Then Mr Thabethe, not really sure of his name, came from the Department, and he told us about GeoGebra here at school. It was two years ago.*

Mr Maziya's first encounter with GeoGebra was passively at a teachers' workshop. Later he was formally introduced to it by the official from the DoE. I explored Mr Maziya's view on GeoGebra in teaching mathematics. Mr Maziya described GeoGebra as software that had Java scripts and therefore one needed Java scripts to use it.

> *It's a software package. In the package there is Java script, because it seems like GeoGebra needs us to install Java scripts.*

Mr Maziya further described GeoGebra as a software package that served as a model to display the application of mathematics concepts. He believed that GeoGebra added excitement to learning because learners got to see different ways of learning.

> *I think it displays … it serves more or less as a model. Or, how can I put it? I mean, learners learn better by seeing things, so when they see the projector and they think there's GeoGebra … so, it's inspiring them just to see that, oh we have another way of teaching things, you know? And they would rather see, they see instead of just talking. If they are seeing part of it, I guess it's interesting to them, and interesting things also saves time.*

Mr Maziya continued to explain that GeoGebra was an important tool in demonstrating the application of mathematics, especially in comparison to illustrating concepts with pen and paper.

> *The one thing interesting about GeoGebra, they want to know [the] application of mathematics in real-life issues because when you draw with a pen on the paper, say some about the angles subtended by the arc. So there, when you see that on paper but not really understand ... But when you use GeoGebra, it makes sense. They can see what you mean.*

Mr Maziya was emphatic when he declared that GeoGebra was important in helping learners understand mathematics concepts better. When asked what he would want other mathematics teachers to know about GeoGebra based on his experience of using it, he mentioned the following:

> *I would want them to know that when you teach using GeoGebra, it is good for the learners because from my experience, they easily understand concepts and it saves your time, yeah. And, yeah, you can teach a number of topics using GeoGebra. Because learners … when you teach a concept and then you don't demonstrate a lot … and when you demonstrate the concept, you can see the improvement.*

Mr Maziya continued to talk about GeoGebra and mentioned that he was able to save time when teaching mathematics using GeoGebra. He mentioned that when he taught functions, he would put the grid on the board and this would save time instead of writing on the board. Also, GeoGebra is able to draw graphs instead of the teacher drawing the graph.

> *Right, so when I use GeoGebra, then I would use the grid on the board. But GeoGebra saves time because you can draw on the board. So, I can show on the grid that the sketch that I am talking about ... But then GeoGebra would draw the graph, and then I would show on the graph that this is how you could … and this is how the graph comes out.*

Most research studies show that teachers struggle to integrate technology into their teaching; therefore I explored whether Mr Maziya had encountered any challenges in integrating GeoGebra. Mr Maziya mentioned that he had challenges in integrating GeoGebra. The first was that he had had limited training in using GeoGebra as part of teaching.

> *You know ... it will be nice if that guy who gave us GeoGebra can come again. Just show us what this can do. Or maybe if there was a PLC [professional learning community] where one can discuss and learn more about GeoGebra. I don't like using it [GeoGebra] sometimes because I am not sure of what I want to do.*

A follow-up question was posed to gather examples of how he struggled to use GeoGebra. He mentioned that one challenge was when he wanted to use GeoGebra to teach trigonometry. He struggled to input the sizes of angles, especially because he believed he had to write the 360 degrees angle in terms of 2pi radians.

> *I have tried it in trigonometry as well. I used it sometimes but not up until I realised that I can't write 360 degrees. Specifically, it's from that point of pi radians. For example, a circle has 360 degrees or 2pi radians.*

Other than his struggle to represent angles in GeoGebra when teaching a trigonometric section, Mr Maziya mentioned that he also struggled with labelling information on the graph drawn using GeoGebra.

> *And also there is another issue of labelling the items there in the program, like when I have a circle and I want to label some point, there was a time when it was too difficult. I ended up doing it but somehow there are some points I cannot lab. Yeah, I cannot label graphs because I remember trying to use it for functions one time and I couldn't label.*

#### 4.7.1.7 PD and support

There is a need for teachers to develop their pedagogical foundation when integrating technological tools in their classroom. Hence, the South African DoE has created a framework to guide the development of teachers in the integration of ICT. Thus, there was a need to establish the kind of PD that was available to Mr Maziya and other teachers in the integration of GeoGebra when teaching mathematics in a South African high school. Mr Maziya mentioned that the training they had received could not really qualify as training because it was only an hour's training at his school principal's office.

> *The Department sent someone to train us for GeoGebra. It was one hour's training at the principal's office. The trainer came and we were called to the principal's office. We were told he has come to show us the software that will help in teaching mathematics. It was a quick thing. He showed us to click on a few pages, input some equations. I'm not sure if I could call that training. Then [he] left the information package that was downloaded on our laptops.*

Follow-up was done to establish the depth of the training that Mr Maziya had received and perhaps any knowledge that he had gained from that experience. He mentioned that from the little he had seen, he was keen to know more about the software. They were shown various aspects of mathematics that could be learnt using GeoGebra and that motivated him to want to try to use GeoGebra.

> *It was just a quick thing. But I thought, okay … it is interesting. He showed the graphs, drawing the lines and some geometry. I told myself, I will try it.*

Mr Maziya's positive welcome of GeoGebra software, despite the limited training in it, was impressive. I was, therefore, interested in learning how he got the skill to use GeoGebra the way he described above. He mentioned that he obtained videos on Google and sometimes watched YouTube to see how other teachers use GeoGebra to teach specific mathematics concepts.

> *I use YouTube. I use YouTube for maybe if I want to understand a concept better, I would view videos on YouTube on how one approaches a concept. There is a lot of videos about GeoGebra online. Sometimes, I just go on Google; there is a lot of information there. Other teachers show how they do this and that.*

The framework policy on teacher development on the integration of technology emphasises the need to support teachers in integrating technology into their teaching. Mr Maziya mentioned that several organisations offered support in the integration of technology. The National Education Collaboration Trust, founded by South African president, Mr Ramaphosa, trains teachers in various aspects of technology.

*Yes, in terms of the content delivery, there is support from [the] area office, yes, and we also are a NECT school. That is, National Education Collaboration Trust. It's a trust that was founded by the then deputy president, Mr Ramaphosa now. That says business people would want to help in the improvement of mathematics and physical sciences in schools, as well as English. So, they visit schools; they take teachers and they gather us material like question papers.*

I posed a follow-up question to establish how the National Education Collaboration Trust supports teachers in the integration of technology. Mr Maziya mentioned that they had regular meetings with a team from the trust that helped them learn how to prepare a mathematics lesson and question papers and compare the memorandum with what is in the book.

*So, they visit schools, they take teachers and they gather us material like question papers. In a quarter, they are supposed to be visiting us three times, but sometimes, due to logistical arrangements and their workshops and so on, we end up not meeting. At least we know that once a quarter they would be here.*

From the discussion with Mr Maziya, it was evident that the school had received various ICT tools. I found it impressive that a programme had been set up by the president of the country, Mr Cyril Ramaphosa, to support the integration of ICT in teaching and learning. However, crime appears to be a serious challenge where ICT tools are stolen. Furthermore, there is much room for improvement in how teachers could use resources to improve the teaching of mathematics.

#### 4.7.2 Lesson observation – Mr Maziya

The data below have been derived from the non-participatory observation of Mr Maziya's mathematics class teaching with GeoGebra software. Particular attention was paid to the mathematics content, his teaching practice and, most importantly, how he integrated GeoGebra in teaching the chosen mathematics topic.

##### 4.7.2.1 Introduction

The lesson observation taught by Mr Maziya started with a pre-observation interview to gain an understanding of the mathematics content to be taught, the ICT tools that relate to GeoGebra that he had arranged to use, the expected prior knowledge of the learners and any misconceptions on the taught content.

During the pre-observation interview, Mr Maziya said that his mathematics lesson would be based on reflection, rotation and translation. When asked about the learners' prior knowledge, he said that he expected the learners to know about the Cartesian plane and, specifically, to be aware of the part of the Cartesian plane that is negative and the other that is positive. They should also know how to write a set of ordered pairs and how to plot the points on the graph. When asked about the general learner misconception of the content, Mr Maziya mentioned that learners usually confused negative numbers on the Cartesian plane, confusing the negative numbers in terms of direction and negative numbers in terms of operation. I also asked Mr Maziya about the ICT tools that he was going to use as part of his lesson, and he mentioned that he would be using the whiteboard, PowerPoint and a laptop.

#### 4.7.2.2 Teachers' practices in the teaching of mathematics using GeoGebra

Mr Maziya introduced the lesson by explaining to the learners that transformation implied movement or the change in the object in terms of its position. Mr Maziya explained that there were different types of transformations, namely reflection, rotation and translation. He further said that after transformation or movement, the shape of the object remained the same. The lesson started with translation, and then later, he taught rotation. Mr Maziya explained the objectives of the lesson, even though the explanation lacked detail in terms of what the learners should expect to know by the end of the lesson. He did not probe the learners in trying to establish their prior knowledge as a means to establish the information gap and how he could pitch his lesson on transformative geometry at the right level for the learners.

Mr Maziya projected the Cartesian plane on the board and placed an A4 page on the projected Cartesian plane. He noted four points on the Cartesian plane where the A4 page was placed. He then explained to the learners that the A4 page could be moved to the right or to the left. This process of movement is called translation. The original points on the Cartesian plane were $\mathrm{A}\ (-10, 1), \mathrm{B}\ (-2, 1), \mathrm{C}\ (-2, 10)$ and D $(-10, 1)$ He explained the mathematics rule when dealing with translation; for example, suppose the A4 page is being moved two units to the right, the applicable rule is as follows:

$$A(x, y) \longrightarrow A'(x + 2, y)$$

Therefore, with the given movement of the A4 page on the Cartesian plane, the new points after the translation are as follows: →

$A\ (-10, 1);\ B\ (-2, 1);\ C(-2, 10)\ ; D(-10,10)$
$A'\ (-8, 1);\ B'\ (0, 1);\ C'(0, 10); \mathrm{D}'(-8,10)$

To illustrate the concept of reflection, Mr Maziya explained to the learners that reflection was the part of the transformation that created a mirror image of the original image. The reflection depends on the line of reflection. The same line acts as a mirror. He explained that there was reflection along the x-axis and reflection along the y-axis. He then told the learners that there were guiding rules that were applied when the reflection of an object is discussed.

For the reflection of an object along the x-axis, the rule is:

A(x, y) → $A'(x, -y)$

He went on to explain: “When you do reflection along the x-axis, the y-coordinate is the one that changes.”

For the reflection of an object along the y-axis, the rule is

A(x, y) → $A'(-x, y)$

Mr Maziya further explained: “When you do reflection along the y-axis, the x-coordinate is the one that changes.”

From the delivery of the content, Mr Maziya used mathematics content correctly; however, there was too little engagement of the learners to be able to establish how he addressed learners’ errors. The lesson observation in Mr Maziya’s class was shorter than the rest of the observed cases because the resources in his class were a hindrance. For example, the whiteboard was covered with writing stain marks and it was difficult to see the information that was projected.

Mr Maziya had the GeoGebra software on his laptop. However, he only used it to project the Cartesian plane on the whiteboard. He then drew the points and their transformation on the projected Cartesian plane. During the preliminary interview, shortly before the lesson, Mr Maziya indicated that he would use very little GeoGebra during the lesson because he had not used GeoGebra in a long time. He was, therefore, not confident in using it on the day of the class observation. He further blamed his lack of confidence in using GeoGebra to a lack of professional support when it comes to the integration of technology. Hart and Laher (2015) concur that the lack of PD contributes to the lack of integration of ICT tools.

#### 4.7.2.3 Instructional practices or strategies

**a) Teaching strategy**

Throughout the lesson, Mr Maziya was doing all the talking. He maintained a connection with the learners when he asked them whether they understood or not. Mr Maziya did not ask the learners any questions, and the learners never asked any questions themselves. From the observation, Mr Maziya applied the teacher-centred teaching strategy where he was the one who held the knowledge. The learners appeared to be fascinated by the use of all the ICT tools but seemed lost in connecting with the lesson.

**b) Management of assessment**

Mr Maziya did not prepare any form of assessment for the prepared lesson. There was also no assessment given to the learners after the lesson. Assessment is an important aspect of teaching as it gives the teacher an indication of whether learning has taken place or not.

#### 4.7.2.4 Teachers' challenges in the integration of GeoGebra in the teaching of mathematics

During the classroom observation, Mr Maziya brought to class the projector and laptop. He explained that he did not use chalk and board for his lessons and preferred to do his lessons on PowerPoint. During the lesson, some aspects of the lesson were projected on the board. However, the pictures were not clear due to the poor quality of the whiteboard. Mr Maziya explained the mathematics on transformation referring to the prepared PowerPoint slides. Some learners were engaged in connecting the equipment while others were using a special solution to try to remove the stains on the whiteboard. Mr Maziya was making an effort to put the lesson together despite the challenge that the school had with the absence of a blackboard for writing. However, most of the time for teaching and learning was spent trying to keep the projector stable. The whole lesson was focused on the Cartesian plane that was projected on the board. Therefore, any slight movement of the projector meant that the points also moved. Sometimes during the lesson, the points had to be changed to accommodate the unplanned movement of the projector, which affected the whole lesson.

During the interview, Mr Maziya indicated that he advocated for the GeoGebra software, but his challenge was that it was time-consuming to prepare lessons. He, however, hailed its use when drawing mathematics diagrams and conducting a lesson that required a Cartesian plane. During the non-participatory observation, the lesson included the Cartesian plane and I was interested to observe his attitude. Indeed, he used the Cartesian plane from GeoGebra as the central part of his lesson. However, the lesson was let down by the quality of the whiteboard and it was difficult to see the projected diagram. The lesson was also compromised by the projector because it kept on moving, so the projected figure on the Cartesian plane also moved. However, despite all these challenges, Mr Maziya maintained a positive attitude towards GeoGebra.

## 4.8 Summary

Chapter 4 presented an analysis of documents relevant to the study and a detailed presentation of four cases that illustrated the depth of the data as well as the similarities in the emerging themes.

A number of fascinating and unforeseen findings have emerged from the discussion and analysis of the cases. One unexpected finding was that most of the participating teachers who taught mathematics did not have a general diploma or a bachelor's degree in education but had BSc degrees in mathematics or content relating to mathematics. Mr Magwe had a BSc Computer Science and Electronics, Mr Golenyane had a BSc Mathematics and Mr Sebaya a BCom Statistics. All of the teachers had PGCEs, specialising in mathematics. Mr Sebaya and Mr Maziya pursued research in education through honours and master's qualifications, respectively.

The other interesting but disappointing finding was the contextual factors that affected the culture of learning. These factors had a domino effect on the actual integration of GeoGebra and the attitude of teachers towards the integration of GeoGebra software.

These contextual factors included the scourge of teenage pregnancies in schools within the mining communities. The communities in which the schools are located reportedly seem to have social challenges such as teenage pregnancies and criminal activities that result in the theft and vandalism of ICT tools. The criminal activities are of particular interest to this study as three of the four cases have reported either vandalism or theft of ICT tools such as computers and smartboards. This may have a direct impact on the teaching environment and dropout rate of the learners in these schools.

Another intriguing finding was the number of ICT tools that the schools had received from private donors. The participants reported that their schools owned computers and laptops that had been donated by mines and other private organisations. However, all the schools had been robbed at different times. None of the schools currently have computers or laptops for their learners.

The findings from the document analysis indicated that there was a commitment from the South African DoE to ensure the integration of technology at South African high schools. In addition, there was a commitment to supply schools with technological hardware and software tools and the involvement of school management in doing so. However, their efforts lacked realistic implementation strategies of developing teachers in the integration of GeoGebra. All of the participating teachers reported that the PD of teachers in the integration of mathematics software and related ICT tools needed to be improved.

From the interviews, it was established that the participating teachers were well versed in mathematics content and gave very interesting mathematics examples when asked to do so. There was also a consensus on the benefits of using GeoGebra in teaching mathematics. They had an awareness of using GeoGebra in teaching mathematics, but their skills were limited because there was no proper PD in using GeoGebra. The findings also demonstrated that the teachers were keen to use GeoGebra in their teaching if they could be properly trained on how to use it as part of teaching. There was also a consensus that in topics where they used GeoGebra to teach or revise mathematics topics, the learners' performance improved.

The non-participatory observation findings indicated that there was a serious challenge with regard to the dilapidated conditions of some of the classrooms where learning took place. Some of the classrooms had pit holes and dirty walls. In one of the classes, there was no board to write on except for a worn-out whiteboard. However, the teachers still had a positive attitude towards teaching in general and were keen to expose their learners to various forms of technology, including GeoGebra, in learning mathematics.

The data analysis exposed that some themes were repetitive, consequently indicating the views, opinions and experiences of the integration of GeoGebra in teaching mathematics in South African high schools. In the final chapter, the major findings from the data that have been presented in Chapter 4 will be discussed and the relationship between the literature reviewed in Chapter 4 and the findings will be revealed. I shall also discuss the conclusions relating to the sub-research questions and the reflection of the conceptual framework. Lastly, the recommendations of the study will be provided.

# CHAPTER 5: SUMMARY OF FINDINGS, DISCUSSION, CONCLUSION AND RECOMMENDATIONS

## 5.1 Introduction

In the previous chapter (Chapter 4), I provided a detailed discussion of the data analysis using case studies and a document analysis. The main themes informed the discussions that emerged from the analysed documents, stories and experiences of four mathematics teachers who used GeoGebra in teaching mathematics in high schools. The formulated interview questions and observation tools were informed by the TPACK as the conceptual framework of this study. The teachers' stories and experiences and my class observations served to highlight some of the major themes that had arisen from the collected data.

In this chapter, I present my findings and discuss the conclusions of the study. I also offer some recommendations. The chapter begins with a brief recap of the study, from a brief presentation of the problem to the research questions and a summary of the methodology that has been used. This is followed by a summary of the key findings. Thereafter, I discuss the implications and offer some recommendations. I shall also propose and discuss the modification of the conceptual framework to that of Kohler et al. (2006) based on the data provided by the teachers who participated in this study. Finally, my suggestions for further research in the integration of GeoGebra in the teaching of mathematics in South African high schools are provided.

## 5.2 Summary of the study

The study examined how teachers integrated GeoGebra in the teaching of mathematics in South African high schools. The study explored their perceptions and practices in the integration of GeoGebra, their views on PD and the advantages it awarded them in enhancing their knowledge and skills in integrating GeoGebra in their teaching of mathematics within a South African high school curriculum context. The study was motivated by the global outcry with regard to the poor performance and outcomes in mathematics in many countries and the need for scientific technological advancements that require mathematics as the foundation. Mathematics performance in South African high schools is averaged at 30% to 40% per grade. According to the 2015 TIMSS results, South African school learners rank among some of the worst-performing students in the world. Reddy et al. (2015) are of the opinion that the economy of a country is judged by its performance in mathematics education. Mathematics is regarded as a very important subject because of its link to everyday life and its integral purpose relating to other subjects, such as science, geography, history, business and finance. Therefore, with the rising concern about poor mathematics performance, the integration of ICT in the teaching of mathematics is part of the intervention strategy proposed (Azlim et al., 2015; Maboya, 2015). However, there is a view that the integration of technology is a challenge to most teachers. Koehler et al. (2009) argue that education practices would be enhanced if teachers could use ICT software to facilitate their role and utilise these programs as teaching strategies. Proposed challenges in the actual integration of technology are a lack of ICT skills, inadequate pedagogical training and poor motivation. Most research work focuses on the integration of ICT without making a distinction between hardware and software. Hence, the intention of this study was to engage teachers as the key role players in how they integrated GeoGebra software in their teaching, in particular the teaching of mathematics in high school.

The study employed a qualitative research approach to unpack the views and perceptions of teachers using document analysis, semi-structured interviews and class observation. The interview schedules used in this study were made up of questions aligned to themes on the teachers' background, their content and pedagogical knowledge, their perceptions of their technology and mathematics software and the link thereof to the South African high school curriculum and, lastly, their views on teachers' PD and support in the integration of GeoGebra. Some of the questions forced the participants to dig deeper into their memories, and the interviews provided valuable data that proved to be useful for the purpose of this study. The class observations also provided first-hand insight into the teachers' mathematics knowledge and their pedagogical skills in teaching with GeoGebra.

The TPACK approach influenced the data collection and analysis in the study. This approach was also used to gain a better insight into the perceptions and practices of teachers in how they integrate GeoGebra software (cf. Chai et al., 2011).

The premise of this study was that it is vital to understand the integration of GeoGebra from the views and experiences of teachers. The main aim of this study was to explore how teachers integrated GeoGebra software in the teaching of mathematics in South

African high schools. The study specifically addressed the following research questions:

- What are teachers' perceptions of the integration of GeoGebra in the teaching of mathematics in South African high schools?
- What are teachers' practices in the integration of GeoGebra in the teaching of mathematics in South African high schools?
- What kind of professional development (PD) (if any) is provided to teachers in teaching mathematics using the GeoGebra software in South African high schools?
- How can we account for teachers' understanding of and practices in the integration of GeoGebra to teach mathematics in South African high schools?

My intention was to explore the perceptions and practices of teachers who had actually participated in training on GeoGebra software and who used GeoGebra in teaching mathematics within the South African high school curriculum. With TPACK as the framework, I conducted an intensive study while making sense of how GeoGebra could be better integrated into the South African high school curriculum, if at all, as a part of the strategies that seek to improve mathematics performance. I therefore sought to explore teachers' perceptions, practices and level of PD in order to answer my research questions. I planned, in particular, to explore how teachers integrated GeoGebra, their skills in and knowledge of GeoGebra and how they used GeoGebra and ICT tools relating to GeoGebra to teach various high school mathematics concepts. I also intended to examine the documents relating to the planned lessons and any supporting policies towards the integration of GeoGebra in a mathematics classroom. I furthermore envisioned observing teachers in action while actually integrating GeoGebra in teaching mathematics. In addition, I observed their practices when engaging with learners in their teaching with GeoGebra.

The study explored teachers' knowledge of the mathematics content, which is relevant and foundational to teaching mathematics in the South African high school curriculum using GeoGebra. The study further explored their skills and abilities in the use of GeoGebra as an ICT tool, the challenges thereof and the kind of PD provided to teachers in the integration of GeoGebra in mathematics teaching. To this end, four teachers shared how they taught functions, geometry and trigonometry using

GeoGebra. Finally, with the aid of the teachers, I explored the level of PD they had been provided with in GeoGebra and how it could be improved to ensure efficient integration of ICT in the teaching of mathematics and, consequently, better performance outcomes.

This study contributes to broadening the horizon of the body of knowledge in the teaching and learning of mathematics and may enhance teacher effectiveness and learner performance in South African high schools through the integration of software in general and GeoGebra in particular.

## 5.3 Key findings and the significance thereof

In this section, I discuss the key findings that have emerged from this study. These major findings are as follows: (1) contextual factors affecting the integration of GeoGebra in the teaching of mathematics; (2) mathematics homework; (3) pedagogical knowledge of mathematics software tools; (4) teachers' perceptions of GeoGebra in the teaching and learning of mathematics; and (5) PD support in the integration of GeoGebra. These discussions are conducted in the context of existent literature, and with a bias towards the South African schooling system.

### 5.3.1 Contextual factors affecting the integration of GeoGebra

The first major finding was about the most commonly identified contextual factors that had an impact on the integration of GeoGebra in the teaching and learning of mathematics within a South African setting. These contextual factors are school security to retain ICT tools, absenteeism due to a high teenage pregnancy rate and management support in the school environment. In terms of the integration of GeoGebra software in the teaching and learning of mathematics, the teachers I interviewed pointed out contextual factors that had an impact on their teaching of mathematics at their schools. Jacobs et al. (2018) attest that the integration of technology is context-based, whereby there is a prerequisite to consider the classroom, school, community and environmental factors from which the learner emerged. The integration of mathematics software such as GeoGebra needs to be explored with an understanding of the teacher's CK of mathematics, technology and other ICT software tools (Bu et al., 2013). Hence, the first finding stemming from this study is that there are contextual factors that impede the integration of GeoGebra in the teaching of mathematics in high school within a South African setting. From the interviews with and observations of the participants, the study reveals a complex myriad of contextual factors that have an impact on teachers' integration of GeoGebra in their teaching of mathematics.

#### 5.3.1.1 School security to retain ICT tools

Research indicates that South African schools have received computers, tablets and whiteboards from private donors and non-governmental organisations; however, these tools gather dust, as they remain unused by the schools (Assan & Thomas, 2012; Van Wyk, 2014). The teachers that I had interviewed cited concern over security at their schools over the ICT tools that had been donated to their schools. These tools had either been stolen or vandalised at the school premises in contrast to the predominant belief that ICT tools were there but not used. In addition, once stolen, these tools had never been replaced and, consequently, learning with the integration of ICT tools was permanently compromised, as some of the teachers reflected. Moreover, Sedibe (2011) notes that some schools lock their computers away in storerooms because of the fear that they could be stolen, so neither the teachers nor the learners can use them.

The integration of GeoGebra is further compromised because it would benefit learners if they also had the opportunity to explore GeoGebra independently. The participants unanimously raised the issue of learners' lack of ICT tools due to security issues. There were common instances where schools had received computers, interactive whiteboards and tablets that were later stolen.

Mr Maziya reiterated a similar experience, with his school lacking ICT tools directly being linked to the theft of computers from the school. He added that it was frustrating because no one was ever held accountable for the theft even after having reported it to the authorities. Mr Golenyane also cited concern about the ICT tools such as the interactive whiteboard from his school having been vandalised. The interactive whiteboard is a valuable ICT tool because it is versatile in its use. With the interactive whiteboard, learners are able to actively engage with the content, receive instant feedback on what they are working on and manipulate the learning objects (Manny-Ikan et al., 2011). The whiteboard is also useful in working with GeoGebra, even just to observe and experiment with some features in GeoGebra. Mr Sebaya shared the sentiment expressing the view that the absence of computers was affecting his attitude in using GeoGebra for teaching. He indicated that he was reluctant to use GeoGebra in his mathematics lessons because the learners had no access to computers.

The loss of ICT tools through theft and vandalism highlights an environmental factor that is a hindrance to the integration of ICT and, especially, GeoGebra. GeoGebra would be more beneficial to learners if they could also have an opportunity to experiment with the mathematics concepts themselves. Jacobs et al. (2018) affirm that economic and social factors form a context aspect of education in South Africa because of the gap that exists between those who have and those who do not. Culatta et al. (2014) add that the absence of technology at schools compromises learners' success in the 21$^{st}$ century. The participants reflected on the theft of computers as a compromising factor in the integration of any form of technology in the teaching and learning of mathematics. This reflected on weakness in the security systems and the fact that the schools did not have insurance for their ICT tools. Hence, once these valuable items had been stolen or vandalised, they could not be replaced. The teachers and learners had to revert to teaching without ICT tools, which could be demoralising and affect their attitude towards learning.

A huge investment in technology in South African high schools has been made to improve learners' performance. As has been discussed in Chapter 2, organisations such as Connectivity and SchoolNet, which are popular in the North-West Province where the research has been conducted, have been involved in donating ICT tools to schools (Assan & Thomas, 2012). However, South Africa is experiencing a high crime rate, with over 50% of the reported crimes relating to burglaries (Stats SA, 2017). More research is needed to highlight the impact of crime on the state of mathematics education in South African schools, but it can be assumed that the overall impact is negative. Moreover, Trucano (2015) postulates that for fear of them being stolen, some schools lock their computers away in storerooms, where neither the teachers nor the learners can use them.

In addition, the inadequate availability of computers for learners has a negative impact on teaching and learning in that teachers get frustrated and discouraged from using ICT and software packages such as GeoGebra in their educational practices. Akbulut et al. (2011) further point out that the learning environment and lack of ICT resources have a direct impact on the integration of ICT in teaching and learning. This may provide some perspective to adopting traditional teaching methods that suppress the development of learners' higher-order thinking skills, creativity and problem-solving skills and all the other important qualities for a 21st-century learner.

#### 5.3.1.2 Absenteeism due to a high teenage pregnancy rate

There was a consensus among the participants that schools within mining communities were experiencing a higher rate of teenage pregnancy and this had a direct impact on learners' attending school in general. Mathematics is a subject that requires continuity, and so, when learners are not consistent in attending school, it affects their basic understanding of mathematics and, consequently, their ability to appreciate the integration of technology in their learning. The general culture of learning was slowly deteriorating and the rate of absenteeism increasing. Mr Magwe and Mr Maziya held the view that the community around the school had a bearing on the increase in the pregnancy rate. They were of the view that the proximity of the mines had a strong correlation with the high pregnancy rate observed. Several studies (e.g. Macleod & Tracey, 2010; Malahlela & Chireshe, 2013; Matlala et al., 2014) have shown that learning is compromised in schools where there is a high rate of pregnancy.

In my study, compelling evidence was provided of teenage pregnancy and the impact thereof on a subject, such as mathematics, that needs continuity. This is also an indication of the need for social workers to work closely with schools to establish the source of the problem. Mr Sebaya shared the same sentiments when he counted the number of teenage pregnancies at his school to be about 10 learners, with some of them being Grade 8 learners, who are girls of about 13 years of age.

The evidence provided illustrates that the participating teachers believed teenage pregnancy was influencing the teaching and learning at their schools and, consequently, has had an impact on the integration of GeoGebra software in their teaching of mathematics. It is difficult to imagine a situation where a learner is not able to concentrate in class because she is worried about her baby or has to leave school early because she has to attend the prenatal clinic. Glynn et al. (2018) confirm that teenage pregnancy weighs heavily on girls because, among many factors, they lose their confidence and, thus, high levels of stress are reported, which result in either failure or dropping out of school. Indeed, it is not far-fetched to think that a high rate in pregnancy will affect the continuity in learning of mathematics and, consequently, have an impact on the teaching practices of teachers. Teachers' PCK is measured by their ability to address the deficiencies in knowledge of the learners' CK and having the skill to assist them to understand. Therefore, it would pose a challenge to a teacher's lesson plan if the learners who attend class were not consistent or their ability to concentrate was compromised.

#### 5.1.1.3 School environment – management support

In Chapter 2, I discussed the commitment of the school administration as an important factor in facilitating the integration of technology. Al Achhab Sakina (2013) describes the commitment of the administration to include the support that the school management needs to provide to teachers. The school management needs to procure and ensure that the resources are in good working order and that teachers have the skills to use them. In this study, I found that at all the participants' schools, they had only one projector to use for the entire school.

All of the teachers had access to a projector and a laptop, with some indicating that they owned either a tablet or a smartphone that they also used as part of teaching and learning. The teachers I interviewed indicated that they preferred using the projector when integrating GeoGebra in their mathematics lessons. However, all of the schools had only one projector per school and that meant that at times the projector would not be available when they wanted to use it.

This indicates that if the teacher plans a lesson that incorporates GeoGebra through the projector, there would be no guarantee that the lesson presentation would take place as planned. This kind of uncertainty would be demotivating to teachers who are keen on the integration of GeoGebra as well as other ICT tools in their teaching of mathematics. Mr Magwe mentioned that he found value in using the projector, but the challenge was that there was only one projector. Mr Magwe was showing his willingness to integrate ICT tools in his teaching. However, the resources being limited, such as one projector for the entire high school, is a hindrance and has a demoralising effect on the efforts of teachers who are willing and trying to integrate GeoGebra in their teaching.

The key finding in this study has been that there are contextual factors that influence the integration of GeoGebra software. The factors are the learners' lack of ICT resources due to school safety, high teenage pregnancy rate, lack of management support, and lack of formative assessment. These factors do relate directly to ICT; however, they affect the teacher's pedagogical practices. Pedagogical knowledge is an important pillar of knowledge within TPACK (Koehler et al., 2009).

This study advances the found factors which impact on the integration of ICT tools in the teaching and learning environment. The key found contextual factors focus on the software aspect of ICT because the software connects directly with the content subject. It is therefore important to understand mathematics software as the intricate part of mathematics content. Therefore, the availability of ICT tools, the involvement of parents and social factors which impact directly on students are critically important.

### 5.3.2 Mathematics homework

The second major finding of this study was that learners did not submit mathematics homework and, consequently, teachers were not giving their learners homework. The South African mathematics curriculum prescribes informal assessment in the form of homework as a mandatory part of learning. Radović et al. (2019) suggest that regular tasks that report about the work learners have done and the problems they have encountered are an important aspect of teaching with mathematics software. Homework is an important component of any teaching process. It is deemed pivotal in the integration of mathematics software because it is through homework that learners get to practise alone what they have learnt at school. Radović and Passey (2016) further argue that home assignments are the most frequent form of checking learners' knowledge and skills in mathematics. In this study, the participants unanimously agreed that homework was not part of learning in their mathematics teaching. They all agreed that homework was important; however, the learners showed no enthusiasm for that aspect of learning and so the teachers had given up on giving homework.

Mr Maziya pointed out that the learners did not do their homework and the excuse most often was that the home environment was not conducive to learning. Mr Magwe held a similar view on the notion that the learners were not keen on doing their homework; consequently, he avoided giving learners homework. Mr Sebaya agreed with Mr Maziya and Mr Magwe that homework at his school was a challenge and he had resolved to not give learners homework.

The study established that the issue of the absence of homework raises concern because it means learners lack the opportunity to work independently. This lack of homework also affects the integration of GeoGebra because learners need an opportunity to practise independently in order to gain knowledge and skills in their integration of GeoGebra on their own. In Chapter 2 it has been pointed out that Mbati and Minnar (2015) have noted that the integration of ICT fosters the constructivist approach where learners' knowledge needs to be deliberated in the learning process. Goos (2010) further corroborates that when integrating software in the teaching practice, teachers need to find a way to make learners participate in using the software. Therefore, the absence of homework limits the involvement of learners in their learning because they lack the space to reflect on what they have been taught and thus their needs remain unknown.

### 5.3.3 Pedagogical knowledge of mathematics software tools

The third major finding of this study was that the teachers had limited knowledge of mathematics software other than GeoGebra. The participants' responses indicated that their TCK was compromised with respect to the knowledge of mathematics software as the part of TPACK (TCK is the combination of TK and CK). Jaipal-Jamani and Figg (2015) conceptualise TCK as the understanding of technologies that are appropriate for the content that is being taught. This includes teachers' attitude to and skill and level of comfort in using various technological tools. In this study, the participants' knowledge of general software tools included Microsoft Word, PowerPoint and Microsoft Excel. Such software tools might be used in the teaching of mathematics despite the fact that they were not designed for that purpose. One participant, Mr Sebaya, indicated knowledge of another mathematical program, CAS. Knowledge of various software programs strengthens the integration of software in the teaching of mathematics. The participants mentioned that they used Microsoft Word for setting question papers, although they did not use it as part of teaching and learning of mathematics. They, therefore, could not integrate these Microsoft software tools into their teaching.

Mr Magwe said that he used Microsoft Word for administrative purposes. He could not associate Word with the teaching of mathematics. Mr Sebaya also recalled that he used Microsoft Word for setting questions papers.

From the interviews, it was evident that the participants were not aware of how Microsoft Word could be used in the teaching of mathematics. Microsoft Word is a powerful tool in typing mathematics notations and formula. There is also a free downloadable mathematics program, Microsoft Mathematics, designed by the Microsoft Corporation. Microsoft Mathematics is downloadable as a toolbar on Word and can be utilised to assist learners to solve algebra-related problems (Oktaviyanthi & Supriani, 2015). The participants had limited TK in terms of what Microsoft Word could do to enhance mathematics teaching practices.

In Chapter 2, I discussed GeoGebra Spreadsheet, which can be used to create graphs or bar charts using GeoGebra, which is a strong aspect of Microsoft Excel. In the study, I found that the participating teachers had limited knowledge of Microsoft Excel as a program that could also enhance mathematics teaching.

Mr Sebaya used Microsoft Excel sparingly in his teaching, considering that Microsoft Excel could be used not only for data analysis but also to plot graphs and as an assessment tool for modelling tasks.

The evidence provided illustrated that the teachers mainly used Excel for setting question papers. They indicated that they transferred graphs from Microsoft Excel to Microsoft Word, showing their limited knowledge of how other software might be used in the teaching and learning of mathematics. Berenzny (2015) postulates that in order for teachers to have effective skills in the integration of technology in mathematics, they need knowledge of various ICT software. Mathematics software tools demonstrate the manipulation of equations and attention to procedure to show how to arrive at the solution (Iji et al., 2013). For example, the teacher may oscillate between GeoGebra and Excel in a lesson that includes data in statistics content or a lesson based on functions.

This study gives an indication that teachers do explore and use other mathematics software in their teaching of mathematics; however, they mostly have inadequate TPK (for Microsoft Word and Excel). With TPK, they would have a deeper understanding of the use of such tools in their mathematics classrooms. This is contrary to the finding by Mdlongwa (2012) that teachers resist the integration of technology into their teaching, lack the skill to use technology and are intimidated by ICT tools. In my study, most of the participants lacked the knowledge and skill to use particular software for the integration of ICT in their mathematics teaching. However, participants such as Mr Golenyane gave an indication that motivation and intimidation by ICT tools were perhaps not that often an issue in the integration of technology in the teaching and learning environment. The study further revealed that the participants had limited pedagogical knowledge of software tools that could enhance their education practices in mathematics. It is also important to note that software tools in this context are understood as ICT tools. This distinction will be discussed later as part of the justification of a revised framework in the integration of software in the teaching of mathematics.

### 5.3.4 Teachers' perceptions of GeoGebra in the teaching and learning of mathematics

The fourth major finding of this study was that the teachers perceived GeoGebra as a valuable tool in teaching high school mathematics in the South African curriculum. Interview questions were used to examine their views in terms of their knowledge of mathematics (CK, which is a knowledge domain of the TPACK framework) and how they linked their knowledge to what they perceived as being the value of GeoGebra (TK or GeoGebra knowledge, which is a knowledge domain of TPACK). The study looked at the significance of the role of GeoGebra from the examples that the participants gave in describing their experiences of using GeoGebra. During the interviews, the participants expressed the value of the integration of GeoGebra in mathematics teaching. The key valuable factors of GeoGebra, as illustrated in ***Figure 5.1*** below, were as follows: the creation of an exciting learning atmosphere; assistance with visualisation and conceptual understanding; saving teaching time while making accurate drawings; and being relevant in teaching South African high school mathematics (functions and geometry).

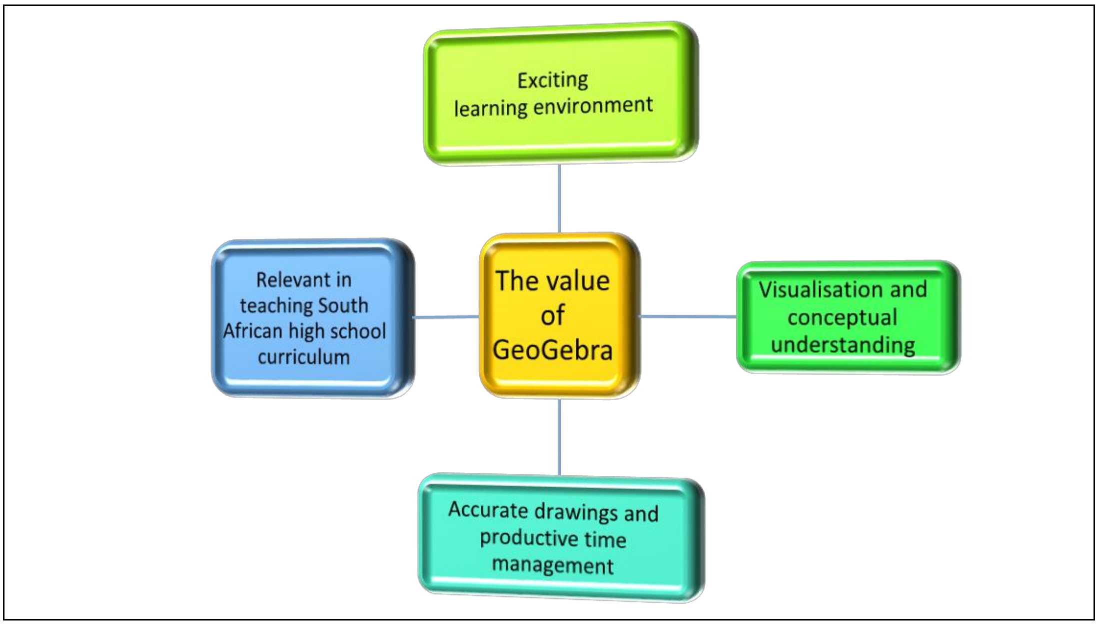


**Figure 5.1: Illustration of participants' views on the value of GeoGebra**

***Figure 5.1*** above illustrates the value of GeoGebra from the participants' objective. The CAPS (2011:8-9) outlines the policy in the teaching of school subjects, including mathematics, in South Africa. When juxtaposing the value of GeoGebra from the participants, as outlined in ***Figure 5.1***, to the and aims and focus content areas as have been discussed in Chapter 2 of the study, according to CAPS (2011), mathematics learning has to include, firstly, aims to bring about "an appreciation for the beauty and elegance of Mathematics". Similarly, the participants believed that using GeoGebra brought about an exciting learning atmosphere in the classroom. Secondly, it brings about a transition from school to the workplace through conceptual understanding. Finally, the amount of information and skills that has to be acquired within a grade is considered. The amount of time and knowledge gained is specific for each grade. ***Figure 5.1*** summarises the perceptions of the participants in terms of what they considered to be the value of integrating GeoGebra within a South African high school context.

The participants indicated that they found GeoGebra to be valuable in constructing an exciting learning atmosphere and enhancing conceptual understanding. Mr Sebaya said that learners got excited at the sight of technological tools. Mr Magwe reiterated that GeoGebra encouraged learners to be enthusiastic about learning and thereby encouraged independent learning. He noted that learners would be eager to share their learning experiences whenever they had tried to work on some mathematics problem independently. This further displayed incorporating a sense of enthusiasm into learning. Mr Maziya also shared this sentiment, indicating that learners would be thrilled by the mention of conducting a mathematics lesson in the mathematics laboratory. As discussed in Chapter 2, Bower et al. (2010) hypothesise that the introduction of ICT in a learning environment encourages an active engagement between learners and their teachers as well as among learners themselves.

From the interviews, it was evident that the learners looked forward to a lesson that incorporated technology. Furthermore, GeoGebra contributed to creating an interactive and exciting learning atmosphere.

From ***Figure 5.1***, it can be gathered that the participants believed that GeoGebra was vital in the visualisation and conceptual understanding of mathematics. The sentiment is shared by other researchers (e.g. Venkataraman, 2012; Zilinskiene, 2014), who confirm that GeoGebra is a valuable tool in helping learners visualise and conceptually understand mathematics. Moreover, the aims of teaching mathematics in the South African context includes a “deep conceptual understanding in order to make sense of Mathematics” (DBE, 2011:8). Similarly, the participants felt that GeoGebra was vital in the visualisation and conceptual understanding of mathematics.

The participants further indicated that GeoGebra was valuable because it helped learners visualise the abstract aspect of mathematics, while also helping with conceptual understanding. Mr Magwe gave an example, referring to teaching abstract aspects of geometry, such as helping learners to understand that there could not be an angle of 180 degrees because 180 degrees lie on a straight line. Mr Golenyane added that learners often struggled with graphs. They often confuse the aspect of the gradient when the graph is increasing or decreasing. He gave an example of how GeoGebra helped learners to visualise that aspect of algebra in learning functions.

From the interviews, it was evident that the teachers perceived GeoGebra to be valuable as a tool that made the abstract concepts in mathematics relatable. As has been discussed in Chapter 2, Azizul et al. (2018) concur that GeoGebra enhances the visualisation and understanding of mathematics concepts for both the teacher and the learner.

As reflected in ***Figure 5.1***, the participants perceived GeoGebra to be valuable in its ability to draw accurate mathematics drawings and helping to manage their teaching time effectively. In South Africa, teachers are expected to spend about five hours per week teaching mathematics (CAPS, 2011). Therefore, the participants found GeoGebra to be valuable in assisting them with time management. The participants further indicated that they found GeoGebra to be valuable in the teaching of mathematics because it allowed them to draw accurate diagrams without spending too much of their teaching time on drawing these. Mr Magwe appreciated GeoGebra because of its feature that helps one get accurate angle sizes. It is difficult to draw an accurate angle size on the board, and inaccurate angle sizes may distort the information, which could ultimately lead to misconceptions in mathematics concepts. Mr Magwe added the example that GeoGebra illustrated and saved time in teaching functions. He mentioned that he would just insert a few instructions on GeoGebra and the accurate Cartesian plane will be available for the learners and then learning could promptly proceed.

During the class observation, Mr Sebaya also illustrated accurate drawing where the learners had to establish the missing size of the interior angle in a triangle when two interior angles were given (***Figure 5.2*** below). The learners did not have to imagine the angle size but could appreciate the visualisation aspect of using GeoGebra. Wheatley and Brown (2012) concur that ICT activities supported by visualisation can expand the learning of mathematics.

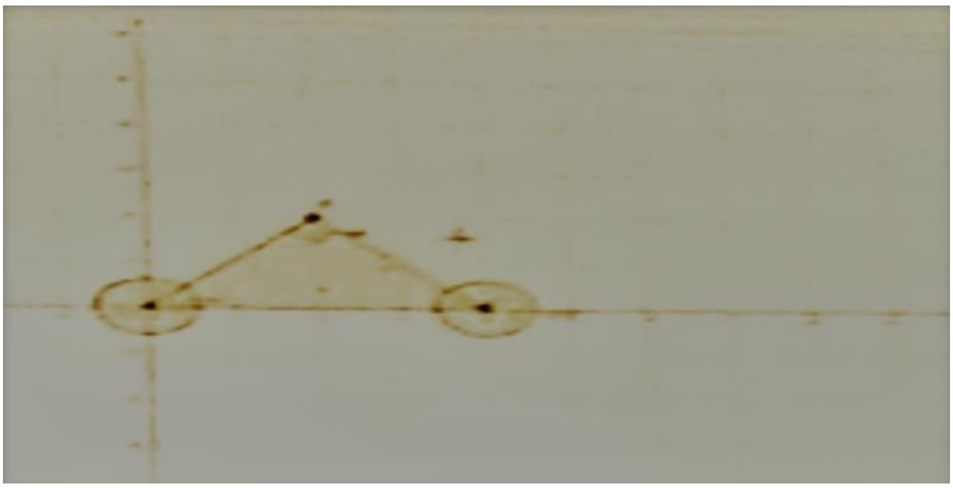

**Figure 5.2: An illustration of visualisation of angle sizes**

From the class observation, Mr Golenyane also assisted learners to conceptually understand the parabola graphs when they were either positive or negative (***Figure 5.3***). As discussed in Chapter 2, Armah et al. (2012) confirm that the benefits of using mathematics software are that technology allows diversion from traditional teaching and encourages gaining a conceptual understanding of mathematics concepts.

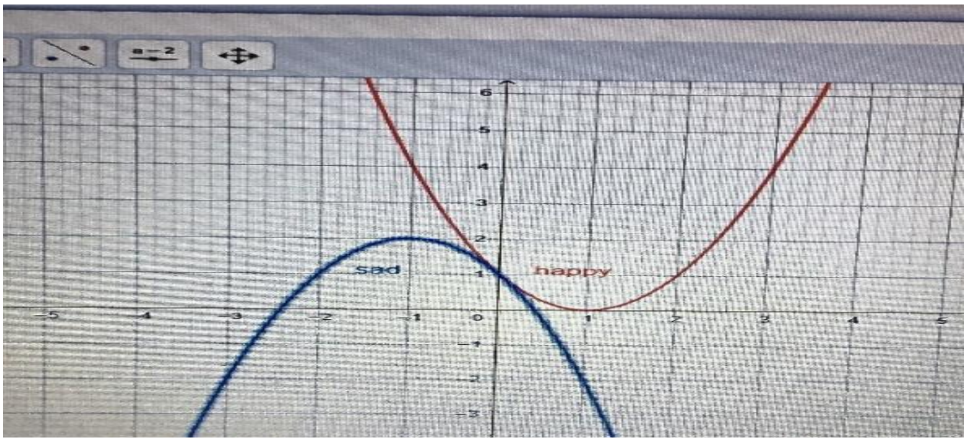


**Figure 5.3: Illustration of parabola graphs to assist learners with conceptual understanding**

The participants appreciated the value of GeoGebra as relevant in teaching mathematics within the South African curriculum (***Figure 5.1***). Most of the participants used GeoGebra in teaching functions and geometry. Mr Magwe indicated that he used GeoGebra in teaching graphs, trigonometry and geometry, which are topics also available in the CAPS document (DBE, 2011). Moreover, the South African curriculum outlines the weighting of content areas, where functions and geometry have significant weights of 35% and 30% respectively (DBE, 2011).

In Chapter 2, I discussed the integration of GeoGebra in teaching Euclidean geometry (cf. Choong et al., 2017). The participants also found GeoGebra to be relevant in teaching geometry. Stols (2012) also holds the view that GeoGebra has excellent illustrative features when it is used to teach geometry. Mr Magwe attested that GeoGebra was relevant in mathematics in a high South African context. Mr Sebaya concurred that GeoGebra was relevant in teaching mathematics in the South African curriculum. Mr Golenyane added that he used GeoGebra for teaching geometry topics to his Grade 10, 11 and 12 learners. Mr Sebaya reiterated the same sentiment – that he found GeoGebra to be valuable in teaching geometry. He used it to teach the properties of triangles. He referred to the names of triangles and the fact that the sum of the interior angles of a triangle equals 180 degrees. Mr Golenyane echoed similar sentiments about the value of GeoGebra. Mr Maziya also hailed the value of GeoGebra in illustrating an abstract concept of geometry to help learners understand the geometric principle of what happened to the angles when they were placed within the circle.

The participants further indicated that GeoGebra was good for illustration purposes in the teaching of functions. Arienda et al. (2017) state that GeoGebra has features that make it easy to find points of functions, such as the roots of the function, the domain and range and for the identification of the gradient. Mr Magwe elaborated on how he used GeoGebra to teach functions, although he demonstrated limited knowledge of how functions might be taught through GeoGebra. Mr Sebaya shared the view that GeoGebra was useful in the teaching of functions and that he appreciated its features. Mr Magwe reiterated that GeoGebra was useful in teaching linear functions and helped learners understand various aspect of graphs.

From the interviews, it was clear that the participants believed that GeoGebra was relevant and good overall for and useful in teaching high school mathematics. However, they also felt that their knowledge of using GeoGebra was limited. Mr Maziya declared that he found value in GeoGebra but he experienced challenges in using it for teaching trigonometric graphs. Mr Sebaya shared this view, indicating that he still had a lot to learn about GeoGebra. He said that he felt he needed more skills in drawing mathematical diagrams and was looking forward to acquiring such skills. Mr Magwe added that using GeoGebra, one needed a lot of preparation time for a mathematics lesson. In situations where he planned to use GeoGebra in a lesson, he had to spend a lot of time doing research and thinking about how he would use GeoGebra.

The participants indicated that they experienced challenges with integrating GeoGebra into their mathematics lessons. These challenges included preparation time, a lack of broader knowledge in using GeoGebra features and the learners' lack of access to computers. The study established that in as much as the raised challenges by the teachers were valid, teachers needed continuous support and they themselves needed to be more committed and willing to put in more effort in learning the GeoGebra features that could enhance their teaching experience.

The overall perception of the participants on GeoGebra gave an indication that they found value in GeoGebra in terms of creating an exciting learning atmosphere. Also, they appreciated its relevance to the South African curriculum.

Furthermore, the teachers perceived GeoGebra to be a valuable tool because it could help learners understand functions, geometry and some aspects of trigonometry. Unfortunately, the examples they gave indicated that they lacked depth and breadth of understanding the extent to which GeoGebra could be used in the teaching of mathematics topics. Still, it was impressive that they recognised the value of GeoGebra because it meant that with adequate training and exposure they would be able to use GeoGebra to its full capacity to the full benefit of their learners. In terms of TPACK, as the assessment of the integration of technology in teaching and learning, the teachers demonstrated an understanding of GeoGebra but needed more knowledge of GeoGebra as a technological tool in teaching such concepts to the full advantage of the software. According to Koehler et al. (2009), there is a knowledge gap with regard to the use of GeoGebra as a form of technology. It was clear from the participants that they endorsed GeoGebra in teaching functions and geometry. They endorsed the illustrative power of GeoGebra that brought about a conceptual understanding of some of the abstract geometry concepts.

### 5.3.5 PD and support in the integration of GeoGebra

The final major finding of the study was on the lack of PD, specifically in the integration of GeoGebra. In Chapter 2, I discussed the PD of teachers as an important factor in the commitment of integration of ICT in teaching and learning. Hismanoglu (2012) postulates that teacher development, which is focused on the training of teachers, specifically on how teachers can integrate ICT in the teaching of mathematics, is necessary. The participants mentioned that they had attended ICT training workshops. However, no workshop training relating to GeoGebra or mathematics software to enhance the teaching of mathematics had been provided.

The study established that the teachers had been given GeoGebra software with minimal support and there was no relevant person they could contact when they experienced challenges. This is in agreement with De Vries et al. (2013), who state that there is a need to strengthen teacher-training policies in developing countries. None of the four teachers that I interviewed could clearly remember the official from the DoE who had offered them training in GeoGebra. They all referred to him as “the guy” or “the gentleman” who offered them GeoGebra training. This is a strong indication of an inadequate relationship and insufficient communication between the teachers and the officials that are responsible for the training of teachers in the integration of GeoGebra. Mr Golenyane recalled a similar experience to that of Mr Magwe of the training relating to GeoGebra. Mr Magwe reiterated that the only time he had seen the DoE official was when he came to introduce them to GeoGebra. Mr Maziya shared the view that the GeoGebra training that they had received was not adequate for them to integrate GeoGebra in their teaching of mathematics with confidence.

From the interviews, it became evident that due to the minimal training on the integration of GeoGebra he had received, Mr Maziya was not confident in using GeoGebra for teaching mathematics lessons. Mr Magwe shared this thought, that even though he believed GeoGebra was a good tool for teaching mathematics, he was sometimes reluctant to use it because he believed he needed more training to be able to use GeoGebra with confidence. Mr Sebaya confirmed the other teachers’ view. He said that he knew less than half of what he believed he needed to know about GeoGebra. He reiterated that the GeoGebra training he had received was unplanned and lasted only a couple of minutes in the principal’s office. Mr Golenyane had similar minimal training in the principal’s office. Mr Maziya shared the same sentiments on receiving minimal training on the integration of GeoGebra in the principal’s office.

From the interviews, it was clear that a brief and weak execution of training in the integration of GeoGebra was done, with no follow-up training having been provided. However, we also note a lack of support from the management if indeed that was the only training received at the principal’s office and there was no intervention from the management for comprehensive training to be provided. However, there is a need for further research to establish the involvement of school management in the integration of GeoGebra. In Chapter 2, I discussed the fact that ICT alone does not translate to success in subjects taught. Tay et al. (2017) outline commitment and school culture as some of the important factors in facilitating the integration of ICT in the teaching and learning environment.

The integration of GeoGebra in the teaching of mathematics involves other ICT tools as well. The study found that, despite the lack of training on the integration of GeoGebra, there had been various organisations that were keen to support teachers in the integration of GeoGebra. Mr Maziya recounted the support that was available from other organisations that focused on offering assistance in teaching and learning, including the integration of ICT in teaching and learning. Mr Sebaya also recalled the professional support that was available to his school to assist the teachers with the integration of technology in the teaching of mathematics and other subjects.

Thus, there is evidence that support was available from private entities for schools to integrate technology in their learning environment. However, there needs to be further engagement with such entities.

## 5.4 Recommendations

The need for the effective integration of GeoGebra is part of an important aspect of the intervention strategy to address the poor performance in mathematics in South African high schools. GeoGebra has been integrated into the mathematics curriculum of some of the better performing countries than South Africa. GeoGebra has recently been introduced as a ICT tool of teaching and learning in South African high schools. Indeed, if mathematics performance is to improve in South African high schools, teachers need to have the necessary knowledge and pedagogical skills to effectively use GeoGebra in their teaching. It is, therefore, important to establish resources from relevant government bodies to assist teachers in dealing with the social challenges that have an impact on the integration of GeoGebra. It is also necessary to strengthen policies that ensure the security of the ICT tools owned by schools. The success of the integration of any ICT tool depends on the teachers. Various studies have looked into the integration of GeoGebra in the teaching of mathematics. Bu et al. (2012:74) recommend the provision of “cognitive support for teachers who may have, self-perceived, negative reaction to GeoGebra” as a necessary step towards the informed and viable use of GeoGebra to improve teaching and learning in mathematics.

Secondly, there is a need for encouragement and support for teachers in using GeoGebra with their learners. Other researchers who support the integration of GeoGebra recommend the use of genuine mathematics problems in learning that includes GeoGebra. Mathematics problems should be carefully identified or formulated according to the mathematical level of learners in that particular grade. The mathematics problems and examples also need to maintain the desired cognitive complexity and pedagogical flexibility appropriate for that grade level (Ljaijko & Ibro, 2013; Martinovic & Karadag, 2012). Other countries call for the integration of GeoGebra into their curriculum (Nisiyatussani et al., 2018). Researchers (e.g. Ljaijko & Ibro, 2013; Martinovic & Karadag, 2012; Nisiyatussani et al., 2018) recommend a good understanding of GeoGebra, how to teach it and support offered to teachers so that they are better equipped to use GeoGebra in teaching and learning.

The present study originates from the view that the integration of GeoGebra needs involvement by and commitment from teachers. Hence, it is important to understand teachers' perspectives on and practices of how they integrate GeoGebra in the teaching of mathematics in South African high schools. Consequently, policymakers and teachers have to explore ways of improving the integration of GeoGebra in high schools. The literature speaks of dealing with social issues that affect the teaching and learning environment. There is also a need for a reformed policy that deals with security issues that leave learners without ICT tools as a result of theft and vandalism. There is a further need for policy reform on the actual curriculum, namely that it should include the integration of GeoGebra. In addition, the policy should strengthen the PD of teachers to be able to integrate GeoGebra software better in their teaching.

As discussed in chapter 2, the study used TPACK as a conceptual framework to explore how teachers integrated GeoGebra in the teaching of mathematics in South African high schools.

The study, as presented throughout this chapter, has uncovered six major sets of findings. These findings provide suggestions for what the participating teachers identified as the best contribution to the improvement of mathematics teaching and learning through the integration of GeoGebra. The study examined the teachers' views and practices and paid attention to the concerns that they had raised.

It is imperative that teachers are engaged in the integration of GeoGebra in their teaching. All of the collected data in this study suggest that in order to effectively integrate GeoGebra in teaching mathematics, there has to be a meaningful engagement and training of teachers. The central thesis of the study is, therefore, that the social issues affecting the integration of GeoGebra should be addressed.

In addition, there is a need to have professional training that is focused on the integration of GeoGebra for South African high school mathematics. Social issues and the theft of ICT resources at schools in poor socioeconomic situations have been shown to have a negative impact on the implementation of ICT and ICT tools in the learning environment. Umameh (2012) strongly recommends better PD of teachers to boost their readiness to integrate technology and to increase their willingness to design mathematics activities and learning strategies with technology. The challenge is to decide which experiences have the potential to contribute to the integration of GeoGebra in the teaching of high school mathematics. Such an understanding and information can only result from comprehensive interaction and collaboration with the teachers. If such interaction and collaboration can be accomplished, the resulting opinions of the teachers must be acknowledged, guarded, respected and then incorporated in the integration of GeoGebra in South African high schools.

The perspectives of the teachers in this study would appear to suggest that teachers value GeoGebra as a mathematics software tool to enhance the teaching and learning of mathematics but have limited skills in and knowledge of GeoGebra and how to teach by applying it. They believed that they could benefit from receiving professional training focused on GeoGebra and learners having access to ICT tools.

The teachers I interviewed, who had received minimal training in the integration of GeoGebra, were expected to use GeoGebra in their teaching of mathematics in South African high schools. Under very difficult circumstances, they succeeded in doing that.

## 5.5 Conclusions

To conclude this study, I examine the conceptual framework of TPACK proposed by Mishra et al. (2006) as a worthwhile framework to gain an understanding of teachers' integration of technology into teaching and learning.

In Chapter 2, I presented the following summary of the TPACK conceptual framework. The framework is about the relationship between technology and teaching. The model presents the interaction of technology and TCK and TPK as pillars of knowledge. It also presents the interaction of technology, content and pedagogy, which is referred to as TPACK. TPACK is the knowledge required for the successful integration of technology into teaching and learning. In the TPACK, the following comprehension of the pillars of knowledge with the interaction of technology is upheld within the model (Jaipal-Jamani & Figg, 2016:140):

> *1. TCK knowledge about different types of activities and models of teaching that are appropriate for using blogs to enhance student learning, and 2. TPK knowledge about how to scaffold teaching of technical skills, while teaching content, were essential for successful implementation of technology-enhanced lessons by experienced teachers.*

In order to introduce GeoGebra as a mathematics software program that can enhance the teaching of mathematics in the South African high school context so that teachers are provided unique PD that is focused on the integration of GeoGebra in the teaching of high school mathematics, I wish to review their model. This review is done with the aid of the findings from the present study of what makes sense in the integration of GeoGebra. Also, pointers as to how GeoGebra may be integrated in the teaching of mathematics in South African high schools are provided. I propose GeoGebra PCK as a modified model for the integration of GeoGebra in the teaching of high school mathematics.

The analysed data indicate that teachers have adequate knowledge of mathematics to teach the subject, as well as skills in and a positive attitude towards technology. The participating teachers had postgraduate qualifications in mathematics and mathematics-related subjects. During the interviews and observation, there was an overall good usage of mathematical language and terminology in their explanations of mathematics examples and teaching. However, challenges with regard to the actual integration of GeoGebra or technology included limited knowledge of and skills in using features of GeoGebra and the teachers struggling with pedagogical skills, which embodied the integration of GeoGebra software. The teachers believed that they could benefit from further workshop training focusing on the integration of GeoGebra. They were also of the view that they needed a better understanding of the various features of GeoGebra. But the overall impression was that they were keen to learn and improve for the benefit of their learners.

To restate, Mishra and Koehler's (2006) framework describes the three important pillars of knowledge (CK, PK and TK), and when these domains interact, they form TPACK, which also inspired Khalil et al. (2017). My modified framework describes the shift from TPACK to a model that is specific to the integration of GeoGebra in teaching analytical geometry.

Chapter 4 and 5 also tried to respond to Mishra and Koehler's challenge of outlining the pillars of knowledge. It was successful to measure the teachers' CK, pedagogical knowledge and TK, which are necessary for the integration of GeoGebra. However, there were limitations in trying to establish the knowledge and pedagogical skills that are important in the integration of GeoGebra in South African high school mathematics. It was, therefore, imperative to consider a revised model of the original TPACK conceptual framework and consider a conceptual framework that could isolate GeoGebra as software and assist in the development of teachers in the integration of GeoGebra software.

In order to implement GeoGebra as a domain of knowledge that is part of technology but unique as mathematics software, Curri (2012) is of the opinion that knowledge of software is important so that the teacher is able to formulate relevant activities and provide a meaningful learning experience for learners.

In conclusion, I therefore present my proposed model that focuses on GeoGebra as a pillar of knowledge – GeoGebra PCK. In ***Figure 5.4*** below, I outline the three pillars of knowledge, which are a modification of the original pillars of knowledge from the TPACK model.

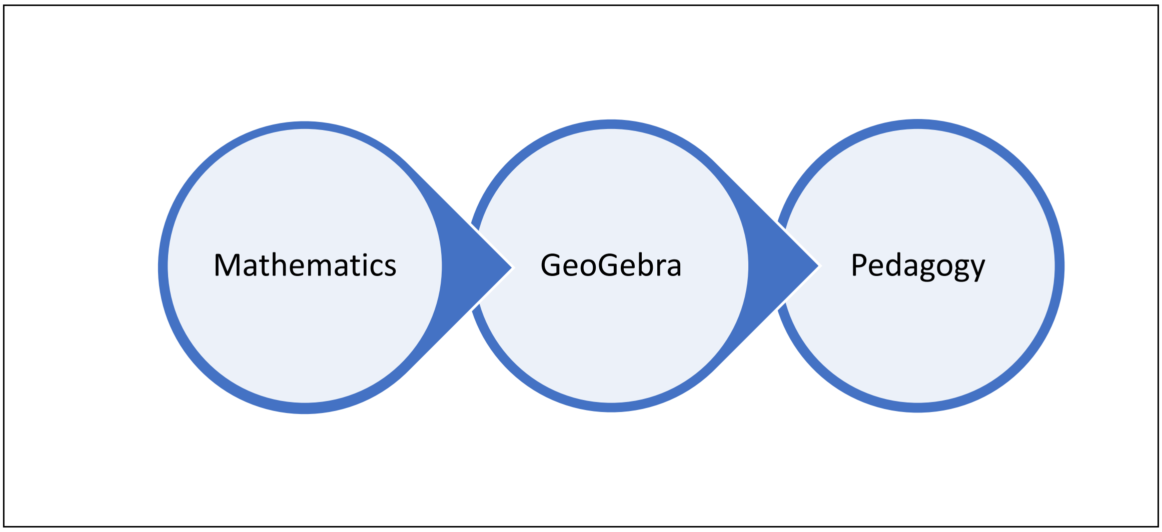


**Figure 5.4: Three domains of my proposed model**

- **Mathematics CK**

Mathematics CK is the organisation of knowledge, as described in the CAPS document, in the mind of the teacher, the understanding of the mathematics content and the different representations thereof and transformation, beyond the facts and concept of a domain (Shulman, 1986).

- **Pedagogical knowledge**

Pedagogical knowledge is an aspect of an education concept that includes a teaching practice skill that is about the knowledge of teaching and how the learning process occurs. It is a reflection or a teaching practice that explains the engagement of learners in a classroom and how the information obtained from their assessment is used to enhance their learning.

- **GeoGebra content knowledge (GCK)**

GeoGebra content knowledge is the knowledge of how to operate GeoGebra software regarding its features, which include function and application. It means expertise in the features of GeoGebra and understanding what teachers can achieve with GeoGebra as a teaching and learning tool. Also, it is knowledge of GeoGebra as an ICT tool that is content-based and may be used for experiential purposes to enhance understanding of mathematics (Binterova & Sulista, 2013).

- **GeoGebra pedagogical knowledge (GPK)**

  GeoGebra pedagogical knowledge is the pedagogy of how to teach and design a lesson for the mathematics content of the high school curriculum to make teaching effective with GeoGebra software. A high school mathematics teacher should know how to simplify the mathematics content through the assistance of GeoGebra. While teaching, he or she should use examples and model the concepts so that conceptual understanding is conveyed to the learners (Isik et al., 2013).

- **GeoGebra PCK for the integration of GeoGebra**

  In the TPACK for GeoGebra to teach high school mathematics through GeoGebra, the four basic principles are as follows: Firstly, teachers should have knowledge of the mathematics content as described in the CAPS document. Secondly, teachers need to have pedagogical knowledge of the mathematics content that they need to teach in high school. They need to have the relevant teacher practice skill that encourages problem-solving skills as required by the CAPS document. Thirdly, they need to plan a lesson in advance that includes the integration of GeoGebra into their lesson. Lastly, teachers ought to have knowledge of GeoGebra as an ICT software tool of choice. They need to understand the GeoGebra features, functions, strengths and weaknesses of teaching specific concepts with GeoGebra.

Below are some recommended steps for integrating GeoGebra into a mathematics lesson. Each step should be part of a proper lesson plan and involve the correct implementation of features of GeoGebra software (Hohenwarter et al., 2008):

- Identify where the lesson will occur; for example, in the classroom or in the mathematics laboratory if the school has one. Such thinking in advance will also help in contemplating learner engagement and assessment.
- State the main objective of the knowledge area. For example, for South African mathematics in high school: numbers, operations, relationships; patterns,

functions, algebra; space and shape (geometry); measurement; or data handling.

- Design the possible plan of action, which can ensure valid results or the achievement of the objective.
- Teaching the concept should be done through a step-by-step process.
- Connect the formulated steps in a coherent manner within the planned lesson.
- Have a concrete plan and then generalise the concept.

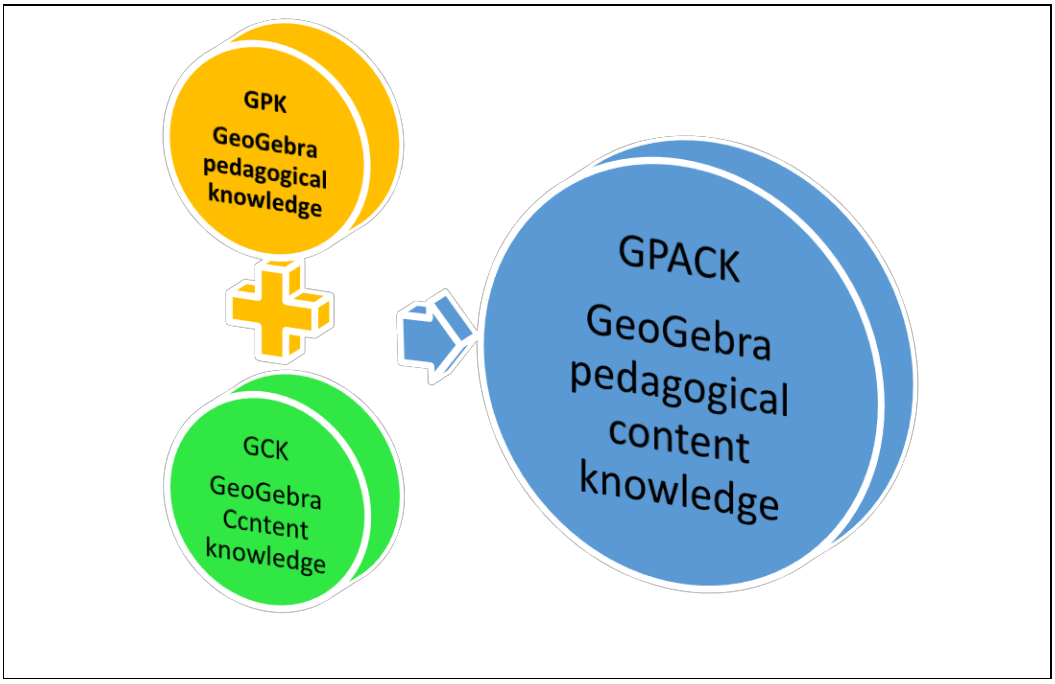


**Figure 5.5: An alternative model for integrating GeoGebra in teaching high school mathematics**

In conclusion, I present my model as a work in progress, in recognition of how we could improve PD targeted at the integration of GeoGebra and measure the success thereof. Teachers believe that GeoGebra can enhance the teaching and learning of mathematics, by helping learners to visualise and gain a conceptual understanding of abstract mathematics concepts. However, dealing with social challenges, addressing the theft of ICT tools and providing teachers with PD in the integration of GeoGebra are important in the quest to improve the performance in mathematics through the integration of GeoGebra. The proposed model seeks to contribute to the improvement of the integration of GeoGebra as a mathematics software tool. The study provides a platform for such work in South African high school mathematics teaching and learning.

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# APPENDICES

## APPENDIX A – INTERVIEW PROTOCOL

**Interview schedule on the integration of GeoGebra software in the teaching of mathematics in South African high schools.**

The study explores how teachers integrate GeoGebra software in the teaching of high school mathematics and their perceptions and practices personally in the context of their work.

By following four teachers who had received training in the integration of GeoGebra software and were teaching mathematics using GeoGebra, I explored the teachers' views, attitude and skills in their teaching of mathematics using GeoGebra since they had received training in the integration of GeoGebra software.

1. Name and background? Your qualifications? How long have you been teaching mathematics? Where? To which grades?
2. Present work experience: School? What is it like to teach at School X? [probe: Why do you say X?]
3. I wish to focus a little bit on your involvement in the teaching of mathematics using technology. When did you start? And with what kind of technology? (probe for each one of them)
4. Take me through how you go about integrating each of the mentioned …
5. What are your experiences with mathematics technology software and specifically GeoGebra? (probe)

   [Describe in detail the topics you actually teach and how you go about it and why.]
6. What challenges do you experience in the use of GeoGebra software in your teaching of mathematics?
7. How do you work together with the other teachers in the integration of GeoGebra?
8. What are two or three of the most important or interesting things about integrating GeoGebra software in your teaching of mathematics? Why do you find these interesting or important? [focus on each one]
9. Did you find the syllabi relevant to your classroom activities?

[How was it relevant? Explain. Use an example if you can to show me how it was relevant for you in your classroom activities.]

10. What kind of support do you receive in the integration of GeoGebra software in your teaching? Who provides it? How is it provided?

11. If you were to tell a story to new teachers about integrating GeoGebra software in your teaching, what would you want them to know about it?

12. Is there anything you think we left out about the integration of GeoGebra software in the teaching of mathematics?

# APPENDIX B – OBSERVATION PROTOCOL

**Non-participatory observation on the integration of GeoGebra software in the teaching of mathematics in South African high schools.**

The study explores how teachers integrate GeoGebra software in the teaching of high school mathematics, and their perceptions and practices personally in the context of their work.

By observing four teachers who had received training in the integration of GeoGebra software and were teaching mathematics using GeoGebra, I explored their practices in their teaching of mathematics using GeoGebra as they had received training in the integration of GeoGebra software.

| **Template to record data during non-participatory observation** | |
|---|---|
| **Pre-lesson interview** | Content of the lesson: |
| | The grade to teach: |
| | Expected time for lesson |
| | Prior knowledge:<br>What do you expect learners to know about the topic you are going to teach? |
| | Resources to use during the lesson. |
| | Any form of assessment. |
| | Lesson plan. |
| **During the lesson**<br>**Observation protocol** | Teacher's ability to communicate mathematics content and correct usage of mathematics language. |
| | Description of the lesson goals and how GeoGebra software is introduced.<br>Skill and knowledge of using ICT tools relating to GeoGebra.<br>Skill and knowledge of using GeoGebra. |
| | Used teaching strategy. |
| | Teachers' reaction to learners when they make a mathematical error. |
| | How GeoGebra is incorporated during the lesson. |

| | |
|---|---|
| **Post-lesson interview (Teachers' reflection on the lesson)** | Ascertain whether the lesson has gone according to plan. |
| | Brief description of the lesson. |
| | Brief description of what went well and any shortcomings. |

# APPENDIX C – ETHICAL CLEARANCE CERTIFICATE

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

**GENERAL/HUMAN RESEARCH ETHICS COMMITTEE (GHREC)**

03-Oct-2019

Dear Mrs Mokotjo, Lindiwe LG

**Amendment Approved**

Research Project Title:
**THE INTEGRATION OF GEOGEBRA SOFTWARE IN THE TEACHING OF MATHEMATICS IN SOUTH AFRICAN HIGH SCHOOLS**

Ethical Clearance number:
**UFS-HSD2019/0113/0106**

We are pleased to inform you that your application for ethical clearance has been approved. Your ethical clearance is valid for twelve (12) months from the date of issue. We request that any changes that may take place during the course of your study/research project be submitted to the ethics office to ensure ethical transparency. furthermore, you are requested to submit the final report of your study/research project to the ethics office. Should you require more time to complete this research, please apply for an extension. Thank you for submitting your proposal for ethical clearance; we wish you the best of luck and success with your research.

Yours sincerely

Digitally signed by Derek Litthauer
Date: 2019.10.03 22:49:32 +02'00'

**Prof Derek Litthauer**
**Chairperson: General/Human Research Ethics Committee**

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**www.ufs.ac.za**

# APPENDIX D – PERMISSION TO CONDUCT RESEARCH

**Education and Sport Development**
Department of Education and Sport Development
Departement van Onderwys en Sportontwikkeling
Lefapha la Thuto le Tlhabololo ya Metshameko
**NORTH WEST PROVINCE**

Garona Building, Mmabatho
1st Floor, East Wing,
Private Bag X2044,
Mmabatho 2735
Tel.: (018) 388-3433
Fax.: 086-514-0126
e-mail: mothabanej@nwpg.gov.za

**OFFICE OF THE SUPERINTENDENT-GENERAL**

Enq. : Dr T Phorabatho
Tel. : 018 388 3071/3433

To: Prof Mokhele - Makgwala
University Free State
Faculty of Education

From: Mrs S M Semaswe
Superintendent-General

Date : 04 June 2019

**PERMISSION TO CONDUCT RESEARCH: MRS LG MOKOTJO**

Permission is hereby granted to your student Mrs LG Mokotjo to conduct research in the department as requested, subject to the following conditions:

- She contacts the relevant School Principals for her target schools about her request with this letter of permission.
- Considering that your research will involve both Educators and Learners, the general functionality of the school should not be compromised by the research process.
- The participation in your project will be voluntary.
- The principles of informed consent and confidentiality will be observed in strictest terms, and
- The findings of your research should be made available to the North West Department of Education and Sport Development upon request.

Best wishes

**Mrs S M Semaswe**
**Superintendent-General**

05/06/2019
**Date**

"Towards Excellence in Education and Sport Development"

# APPENDIX E – LETTER TO THE SCHOOL

P.O. Box 1185
Bloemfontein
9300
Contact no.: 073 872 9175
E-mail: lmokotjo@yahoo.com
July 2019

The Principal

**Request for permission to conduct research at your school**

Dear Sir/Madam

My name is Lindiwe Mokotjo, and I am currently studying towards a PhD degree at the University of the Free State. I hereby request permission to conduct research at your school. As part of my studies, I am conducting a study titled "**The integration of GeoGebra software in the teaching of mathematics in South African high schools**".

This study has the potential to benefit teachers of mathematics in their integration of GeoGebra software and other mathematics software tools. The study will further assist the broader Department of Education and respective policymakers in strengthening the integration of technology and specifically GeoGebra as an intervention strategy in dealing with poor performance in mathematics.

My interaction with the selected teachers will involve 1) an interview of about 60 minutes on each selected teacher and 2) class observation of two lessons on two selected teachers. The classroom observation will be arranged according to the respective teachers' timetables in a way that would cause the least possible inconvenience to the school programme. I shall also review the lesson plans and any relevant information about the integration of the GeoGebra software.

Participation is entirely voluntary, and teachers may withdraw from the study at any time should they wish to do so. I shall observe confidentiality and protect the participants from any harm, physical or psychological. The real names of the schools and the participants will not be used in any reports of the study. At the completion of the study, I shall provide the Department of Basic Education with a copy of the study report.

For further questions, information or suggestions, please feel free to contact me and/or my research supervisor, Professor M Mokhele-Makgalwa, at MokheleML@ufs.ac.za or use the following telephone number: +27 (51) 401 3777.

Thank you for considering this request.

Yours thankfully

Lindiwe Mokotjo

Cell: 073 872 9175

E-mail: Lmokotjo@yahoo.com

## APPENDIX F – INFORMED CONSENT

P.O. Box 1185
Bloemfontein
9300
Contact no.: 073 872 9175
E-mail: lmokotjo@yahoo.com
July 2019

**Mathematics Teacher**
xxx Senior Secondary School
Rustenburg, 0299

**INVITATION TO PARTICIPATE IN THE STUDY**

Dear Sir/Madam

My name is Lindiwe Mokotjo, and I am currently studying towards a PhD degree with the University of the Free State. As part of my studies, I am conducting a study titled **"The integration of GeoGebra software in the teaching of mathematics in South African high schools"**.

The aim of my study is to explore how teachers integrate GeoGebra software in the teaching of mathematics in South African high schools.

You have been identified as a mathematics teacher who is currently involved in the integration of GeoGebra software in the teaching of mathematics and whose concerns, perspectives and practices would help respond to the sub-research questions in my study. This study has the potential to benefit teachers who have access to ICT tools in their schools in how they could effectively use GeoGebra software in their teaching of mathematics. The study will further assist the broader Department of Education and respective policymakers in strengthening the integration of technology and specifically GeoGebra as an intervention strategy in dealing with poor performance in mathematics.

Our interaction for this study is expected to resume from May 2019 to June 2019, with two to four meetings per month. The interaction will involve interviews that will last for more than one hour. Observations will be arranged for the mathematics double period at your school. There will also be a document review of the prepared lesson plans and training material relevant on the integration of GeoGebra software.

Your participation is entirely voluntary, and you may withdraw from the study at any time should you wish to do so. Whether you agree to take part or decline to take part will remain unknown to any third party. I shall observe confidentiality and protect the participants from any harm, physical or psychological. The real names of the schools and the participants will not be used in any reports of the study.

At the completion of the study, I shall provide the Department of Basic Education with a copy of the study report (without the names of the participants or the schools involved). The findings will be shared with you and other mathematics teachers.

Your participation will add great value to this study. Please sign below for consent to participate.

If you would like to participate in this study, please give consent by signing and filling in your details at the bottom of this letter.

Yours thankfully

-----------------------

Lindiwe Mokotjo

Name of participant giving consent……………………………………………

Signature…………………………………………………..

Date……………………………………………………….

School…………………………………………………….

Cell phone number………………………………………..

## APPENDIX G – CERTIFICATE OF LANGUAGE EDITING

# CERTIFICATE OF LANGUAGE EDITING


Dr. L. Hoffman

Kroonstad

BA, BA(Hons), MA, DLitt et Phil, Certificate (English Grammar for Editors)

Member of South African Translators' Institute – No. 1003545

Cell no: 079 193 5256 Email: larizahoffman@gmail.com


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## DECLARATION

To whom it may concern

I hereby confirm that I have proofread and edited the language of the following thesis, including the bibliography.

**Title of thesis**

THE INTEGRATION OF GEOGEBRA SOFTWARE IN THE TEACHING OF MATHEMATICS IN SOUTH AFRICAN HIGH SCHOOLS

**Candidate**

LINDIWE MOKOTJO



Lariza Hoffman

Kroonstad

23 June 2020

# APPENDIX H – TURN-IT-IN REPORT

Final Thesis_Lindiwe

ORIGINALITY REPORT

| 2% | 3% | 1% | 2% |
|---|---|---|---|
| SIMILARITY INDEX | INTERNET SOURCES | PUBLICATIONS | STUDENT PAPERS |

PRIMARY SOURCES

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|---|---|---|
| 1 | uir.unisa.ac.za<br>Internet Source | 1% |
| 2 | Submitted to University of the Free State<br>Student Paper | 1% |
| 3 | scholar.ufs.ac.za:8080<br>Internet Source | 1% |