The influence of GeoGebra training on teachers and learners in rural geometry classrooms

by

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DECLARATION

I, **Collen Manganyana**, student number **15270816** hereby declare that this thesis, "*The influence of GeoGebra training on teachers and learners in rural geometry classrooms*," submitted in accordance with the requirements for the PhD degree at University of Pretoria, is my own original work and has not previously been submitted at this or any other institution of higher learning. All sources cited or quoted in this research paper are indicated and acknowledged with a comprehensive list of references.

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ETHICS STATEMENT

The author, whose name appears on the title page of this thesis received ethical approval from all relevant authorities. The researcher, therefore, declares that all ethical standards and guidelines were adhered to before engaging in the field work.

DEDICATION

I dedicate this research to my wife, my children, my late parents and siblings.

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ABSTRACT

The aim of this study was to investigate the influence of GeoGebra training on teachers and learners in rural geometry classrooms. The conceptual framework that was used in this study was based on the four-level training evaluation framework of Kirkpatrick (1996), focusing on the first three levels only while the fourth level was not considered. The study was conducted in disadvantaged and under-resourced schools situated in the Mpumalanga Province of South Africa. This undertaking was considered as a way of promoting what was perceived as a simple but effective method of teaching and learning with technology. The technology-enhanced teaching strategy was employed with the anticipation of enhancing the development of geometrical concepts that are seen as too abstract by the majority of learners in resource-constrained areas. Hence, the focus of this study was on the teaching and learning of the properties of triangles and the properties of quadrilaterals in Grade 10 using GeoGebra and traditional methods. Within the non-equivalent, quasi-experimental design, both qualitative and quantitative approaches were used. Four purposively sampled Grade 10 teachers from four schools and their classes comprising of 165 learners participated.

The data collection involved pre- and post-tests, questionnaires, lesson observations, and interviews. Learners' achievement was measured by outcomes obtained from marked and recorded achievements tests. The qualitative data collected from the teachers through questionnaires, lesson observations and interviews were coded and categorised into themes. This analysis revealed that most participants had positive training experiences and preferred using GeoGebra in the teaching and learning of geometry despite a lack of resources in their schools. The findings also showed that there was lack of training workshops that focused on appropriate teachers` knowledge and skills that are connected to technological innovations, particularly in GeoGebra. The quantitative data analysis results showed a significant difference in the mean scores for both groups respectively in favour of learners taught with GeoGebra compared to a chalk and talk method. The teachers' implementation of and enthusiasm about GeoGebra had a positive influence on learner achievement. Based on the results, it was concluded that as a pedagogical tool, GeoGebra can work effectively in rural schools where geometry is hardly taught.

Key Terms:

Training evaluation; reactions; learning; behaviour; results; Kirkpatrick`s four level evaluation framework; technology-mediated learning; GeoGebra; pre-post-tests; Geometry.

LANGUAGE EDITOR

Exclamation Translations

To whom it may concern

The thesis entitled, "The influence of GeoGebra training on teachers and learners in rural geometry classrooms" has been edited and proofread as of 14 February 2020.

As a language practitioner, I have a Basic degree in Languages, an Honours degree in French and a Master's degree in Assessment and Quality Assurance. I have been translating, editing, proofreading and technically formatting documents for the past nine years. Furthermore, I am a member of the South African Translators' Institute (SATI) and the Professional Editors' Guild (PEG).

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Kind regards

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LIST OF ABBREVIATIONS

ATP	Annual Training Programme
CAPS	Curriculum and Assessment Policy Statement
CI	Curriculum Implementer
DBE	Department of Basic Education
DGS	Dynamic Geometry Software
DMS	Dynamic Mathematical Software
FET	Further Education and Training
GET	General Education and Training
HOD	Head of Department
MEC	Member of the Executive Council
MP	Mpumalanga Province
MPED	Mpumalanga Provisional Education Department
NCS	National Curriculum Statement
PED	Provisional Education Department
PSMT	Pre-Service Mathematics Teachers
SA	Subject Advisor
SADTU	South African Democratic Teachers` Union
SPSS	Statistical Package for Social Statistics
TLI	Teacher Laptop Initiative

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CHAPTER 1 INTRODUCTION AND ORIENTATION

1.1 INTRODUCTION

The education system in South Africa has experienced many changes since 1994 when South Africa became a democracy. The latest changes saw the introduction of the Curriculum and Policy Statement (CAPS) document (DBE, 2011a) in schools from Grades R-12. Changes to the Grades 10 -12 mathematics curriculum (DBE, 2011a) include the introduction of new and unfamiliar concepts and topics in the curriculum. For example, Euclidean geometry became a compulsory section in the Grade 12 final examination and was examined in Paper 2 from 2014 onwards. In the previous NCS curriculum, Euclidean geometry was an optional topic, and Paper 3, in which it was examined, was not compulsory for Grade 12 learners.

Although introductory geometry has always been compulsory in the General Education and Training (GET) phase (Grade R-9), most teachers teaching mathematics in the Further Education and Training (FET) phase (Grades 10-12) (DBE, 2011a, p. 10) have not taught geometry because it was seen as difficult (Olivier, 2014) and could be left out. The insertion of Euclidean geometry into the new curriculum (DBE, 2011a) in the FET band has also been a challenge to a number of mathematics teachers (van Putten, Howie & Stols, 2010; Siyepu & Mtonjeni, 2014). The challenge still exists because teachers still feel uncomfortable teaching Euclidean geometry content (Masha, 2015). It has also been shown that teachers feel that more training on this content is needed.

The prescribed CAPS document encourages teachers and learners to engage in activities that give rise to higher-order thinking skills (DBE, 2011a). These activities should promote reasoning and encourage the development of problem-solving skills in learners. Thus, the CAPS document aims to promote quality teaching and learning in classrooms. Although the intended curriculum encourages learners to become lifelong learners and to acquire knowledge and skills applicable to their everyday personal, social and work-related life experiences, what is implemented in the classroom is quite different. In actual fact, it is essential to note that there is often a difference between the intended and the implemented curriculum. For example, instead of complying with the recommendations in the CAPS document that advocate for learner-centred approaches, it is business as usual for most mathematics teachers, more so for those in rural schools. This perhaps shows that teachers do not bother with reconstructing their teaching strategies in order to enhance teaching and learning that is supported by the intended curriculum. Contrary to what is currently happening in the mathematics classrooms, one of the possible strategies that could be employed in teaching geometry is using educational technology like GeoGebra.

GeoGebra is a free *Dynamic Mathematics Software* (DMS) that may be used in schools, colleges and universities to teach geometry, algebra and calculus (Yorgancı, 2018). It is written in Java and readily available in more than one language. GeoGebra as *Dynamic Geometry Software* (DGS) is easy to use when doing basic constructions such as geometric points, lines, rays, line segments and polygons. GeoGebra allows one to create and manipulate objects in the drawing window while observing the changing effects in the algebra window at the same time (Bist, 2017). Its introduction in the classroom, however, requires that teachers re-align and re-configure the way they plan and conduct their classroom practices. Despite the challenges that may come along with the use of educational technology, this instructional strategy has been seen to be very effective in the learning and teaching of various geometrical concepts (Ubuz, Ustun & Erbas, 2009).

Although several studies have been carried out on technology usage in mathematics education, Bansilal (2015) admits that limited research has been done in this regard in the South African context as it is falls under the category of a developing country. A few studies conducted in South African schools mainly focus on the learning of geometry in terms of the Van Hiele model (Alex & Mammen, 2016). Thus, in order to contribute to the existing knowledge gap, this study examined how training teachers to use GeoGebra as a pedagogical instrument influences learners' achievement and learning in rural schools.

I investigated how teachers, newly trained in the use of GeoGebra software, could use this technology as a pedagogical tool in the hope of positively influencing learners' achievement and the learning of geometrical concepts involving the properties of triangles and quadrilaterals. The aim was to solicit information that could provide an in-depth understanding of how these newly trained teachers' reactions towards the use of GeoGebra training and its implementation influences the performance of learners. In this study, the achievements of learners taught with GeoGebra were compared to learners taught using only pencil and paper.

1.2 BACKGROUND OF THE STUDY

Learners, teachers, parents, departmental officials and the country at large have been affected negatively when it comes to learners' poor achievement in mathematics (Tsanwani, Harding, Engelbrecht & Maree, 2014). It is clear from reports (DBE, 2009, 2010, 2011b, 2012, 2013, 2014b, 2014a, 2015) and other studies (Spaull, 2013; Spaull & Kotze, 2015) that learners are performing poorly in mathematics. Based on the literature reviewed, several authors are recommending a different approach in teaching and learning which includes the use of ICT, among others (Albirini, 2006; Anderson, 2010; Bingimlas, 2009; Shimasaki, 2015).

Teaching and learning mathematics should be driven by a learner-centred approach (Rambe, 2016; Zhou, Chan & Teo, 2016). The CAPS (2011) document, which replaced the National Curriculum Statement (NCS) Grade R-12, aims to promote a learner-centred approach in the classroom and encourages teachers and learners to engage in activities that give rise to higher-order thinking skills. These activities may promote reasoning and encourage problem-solving strategies. This approach aligns with the anticipated outcomes outlined in the e-Education policy document that advocates for collaborative learning among learners (DoE, 2004), and allows learners to be independent, creative and hence become critical thinkers in the learning process. Even though the aims of the intended curriculum are clearly articulated in theory, they are far from the reality in the classroom as is evident in the actual implemented curriculum. In order to foreground the relevance of educational technologies, the DBE introduced and implemented the e-education policy of 2004 into all South African schools. The Department of Education (now the Department of Basic Education) (DoE, 2010) took this course of action with the aim of "transforming the learning and teaching" (DoE, 2004, p. 1). The result has been a variety of teaching and learning strategies that are associated with instructional classroom practices aimed at enhancing effective teaching and learning.

When the DoE introduced the e-Education policy document, it foresaw an improvement in learners' achievement and teachers' pedagogical classroom practices in specific subject areas beyond the mere development of computer literacy skills. This is made clear in the following excerpt:

> Besides acquiring basic skills in ICT, e-Education enables the user(s) to:

- "Apply ICT skills to access, analyse, evaluate, integrate, present and communicate information;
- Create knowledge and new information by adapting, applying, designing,
  inventing and authoring information; and
- Function in a knowledge society by using appropriate technology and mastering communication and collaboration skills." (DOE, 2004, p. 14).

These objectives conform with the aims indicated in the CAPS document (DBE, 2011a). In line with the proposition in the e-Education policy document (DoE, 2004), the DoE national office immediately developed and implemented a framework that provided guidelines for teacher development in the effective implementation of ICT in the classroom (DoE, 2007). Despite massive efforts by the DoE to promote the integration of educational technology into schools, many secondary schools have not fully benefited from this initiative to date. According to Vandeyar (2015), "The e-Education policy did little to direct provincial and district officials to comply with the e-Education policy mandates and strategies to change teachers' pedagogy" (p. 6). This lack of support from intermediaries may have contributed to this lagging progress in a province like Mpumalanga, which is largely rural and not economically robust (Vandeyar, 2013, 2015).

While the national policy on e-Education is sound, the situation on the ground is completely different. Teachers hold the notion that they were never consulted in the formulation of the e-Education policy by the Department of Education, hence, they passively resist implementing it because it was brought down to them. Teachers also feel that the district officials do not give them any support to ensure the successful implementation thereof, making it a policy on paper but never put into practice in schools (Vandeyar, 2013). In this study it is supposed that well-planned and effective teacher training sessions that focus on professional growth in ICT integration rather than computer literacy training sessions can make a difference.

Although the policy on e-Education has gainfully penetrated the offices of administrators at almost all levels in the functional lines of the department, Vandeyar (2013, p. 4) asserts that it "falls short from achieving the main strategic target of influencing and changing classroom practice." To date, most rural schools in this province have lagged behind in the implementation of technology-mediated instructions when teaching learners. In South Africa, rural refers to sparsely populated areas, for instance, farms, townships and tribal lands controlled by chiefs or headmen. These areas lack basic facilities or services such water, electricity, sanitation, good roads, learning and infrastructure resources, to name a few. In the context of this study, rural schools refer to disadvantaged schools situated in these poverty-stricken areas in the province in which this study took place.

A majority of the learners attending these schools come from poor families with parents who have little or no education themselves and struggle to feed their children. The reason for lack of technology-based learning may thus possibly be that most of these schools have no access to computer facilities and, in some cases, there is no electricity in the classrooms. This lack of computer facilities and other resources (Ndlovu & Lawence, 2012) may have contributed to continuous poor performance in national examinations, as evidenced by diagnostic reports (DBE, 2009, 2010, 2011b, 2012, 2013, 2014b, 2014a, 2015). However, in an attempt to improve on fairness regarding access to quality education in public schools, the government amended the South African Schools Act in 2005 and introduced a quintile system.

A quintile system uses five categories to rank public schools in each province from the poorest to the most affluent. For example, quintile 1, 2 and 3 schools cater to learners from the poorest communities situated in deep rural and township areas. These schools receive funding from the government because they are classified as non-fee paying schools. Alternatively, quintile 4 and 5 schools serve the wealthier communities and receive little financial support from the government because they are allowed to charge school fees. Despite varying conditions in schools, researchers such as Lundall and Howell (2000) have supported the use of technology as an instructional strategy in the mathematics classroom.

Furthermore, Hennessy, Onguko, Harrison, Kiforo, Namalefe and Naseem (2010) and Onuoha, Ferdinand and Onuoha (2015) state that studies conducted both locally and globally show that technology-rich environments provide direct interaction with technology and instant feedback, thus promoting effective teaching and learning. Several researchers (Akanmu, 2015; Bhagat & Chang, 2015; Özçakır, Aytekin, Altunkaya & Doruk, 2015; Zhou et al., 2016) have investigated the effects of the GeoGebra software program in mathematics. Since I did not find studies conducted locally using Kirkpatrick's framework on how teachers who are newly trained in the use of GeoGebra are enabled to influence learners' achievement in geometry (Koehler &

Mishra, 2009), this framework was found relevant for use in this study to assess the effectiveness of GeoGebra training in the performance of learners.

Guided by the current existing knowledge gap, this study investigates how the implementation of GeoGebra training by teachers who are newly trained in its use influences their classroom practice. The study also explores the impact of this implementation on learner experience and achievement. This program allows learners to observe manipulated objects in a dynamic visual environment while translation to numeric representation occurs at the same time. Emerging evidence from the research indicates that opportunities to manipulate objects in a visual environment can improve learners' development of cognitive skills (Richardson & Koyunkaya, 2017). In this study, the use of GeoGebra represents a technology-mediated approach to teaching and learning, while the simple use of chalk, pencil and paper represents the traditional approach.

1.3 PURPOSE OF THIS STUDY

The purpose of this study was to investigate how the implementation of GeoGebra by teachers newly trained in its use influenced their classroom practice. The impact of this implementation on learner experience and achievement is also explored. In order to achieve this purpose, data were collected through questionnaires, in-depth interviews and achievements tests at locations convenient to the participants.

1.4 PROBLEM STATEMENT

The CAPS document encourages the use of technology in mathematics classrooms (DBE, 2011a). Research has shown that effective teaching in schools through the use of technology has the power to improve learner achievement and learning, and hence promote education (Akintade, Ogbonnaya & Mogari, 2015; Aksoy, 2013; Overbay, Mollette & Vasu, 2011; Stoilescu, 2014; Yigit, 2014). However, the use of educational technology in some non-fee paying schools (quintiles 1, 2 and 3) situated in the disadvantaged rural areas is almost non-existent, although the government has supplied these schools with computer laboratories. Although the availability of GeoGebra in rural schools is not a problem; a lack of training and competence in its use in order to cope with the goals of the intended curriculum and "buy in" of the teachers and learners is a problem. In light of this, rural mathematics teachers are confronted to translate the goals of the intended curriculum into actual classroom practice. The usefulness of GeoGebra in teaching geometry is well documented. The question, however, remains: do teachers newly trained in the use of GeoGebra possess the skills and determination to successfully modify their teaching practice to include this technology in a rural geometry classroom to increase learner performance?

Studies conducted by several researchers have concluded that most mathematics teachers still struggle with the effective implementation of technology integration when teaching mathematics in their classrooms (Chai, Koh & Tsai, 2013; Davidson, Richardson & Jones, 2014; Escuder & Furner, 2011; Leendertz, Blignaut, Nieuwoudt, Els & Ellis, 2013). In spite of the challenges, increasing the effective use of dynamic tools and resources has been a national goal since the inception of CAPS in January 2012. However, technology should not be used as a mere productive tool, but also as a tool to promote and enhance learner creativity in the classroom (Mudzimiri, 2012). However, the tension created between the intended curriculum and the actual implemented curriculum in the classroom offer the opportunity for the creation of new knowledge. As already discussed, this study sought to investigate how the implementation of GeoGebra by teachers newly trained in its use influenced their classroom practice. The impact of this implementation on learner experience and achievement is also explored.

1.5 Rationale

As an in-service teacher, I integrated GeoGebra software into my teaching of Euclidean geometry in Grade 10 mathematics classes. Learners whom I had taught previously had struggled with understanding the content in Euclidean geometry, and this forced me to be innovative as a teacher. Since introducing GeoGebra into this section of the curriculum in 2013, my class average has moved from 32% to 46% in 2014 and 56% in 2015. I did not teach Grade 10 in 2016 and 2017. The statistics provided indicate that the performance of learners whom I taught significantly improved in terms of their cognitive skills development, creativity, and collaboration with peers. A review of the literature showed that when GeoGebra is properly implemented in the classroom, then the intended goals of the curriculum are achieved. Several studies consulted locally and globally indicate that the performance of learners taught with GeoGebra in various mathematics topics increased compared to the traditional teaching strategy (Kushwaha, Chaurasia & Singhal, 2014; Mushipe & Ogbonnaya, 2019; Shadaan &

Leong, 2013). The reality evidenced in South African rural schools is that computers are not readily available in classrooms (Howie & Blignaut, 2009), although, the existence of free technologies may provide users with access to several innovations. For instance, the simple use of a laptop, data projector and free GeoGebra may enhance teaching and learning.

Despite efforts by governments all over the world to support the inclusion of technology into the mathematics curriculum, it is so sad to note that it still needs to be fully incorporated in rural classrooms (Chigona & Chigona, 2010; Dube, Nhamo & Magonde, 2018; Khokhar, Gulab & Javaid, 2017). It is apparent that technology (GeoGebra) has been successfully incorporated into mathematics teaching and learning the world over, nevertheless, its influence in rural schools is yet to become a reality. While CAPS and the e-Education policy requires teachers to alter their teaching strategies and use relevant technologies to improve learning, it is clear that a lack of training hinders their ability to enforce it in their schools (Howie, Muller, & Paterson, 2005).

Furthermore, the use of GeoGebra within the context of rural schools in South Africa is still in its inception stage. This means that limited literature is available concerning training and its use in the classroom, as well as the influence of training on the performance of learners. This gap between the curriculum proposed by the DBE and the curriculum implemented by the teachers suggests that there is a need for teachers to be trained in the use of GeoGebra as a way to make teaching and learning better. Accordingly, the aim of this study was to provide knowledge on how effective training in the use of GeoGebra for instruction may change classroom practice.

1.6 RESEARCH QUESTIONS

The research aimed to answer the following main question:

- How does the implementation of GeoGebra by teachers newly trained in its use influence their classroom practice as well as learner experience and achievement in the geometry classroom?

The following sub-questions guided this research in seeking answers to the overarching research question:

1. How did the teachers react to their training in the use of GeoGebra?

2. How did the teachers implement their training in the classroom?
3. How did the learners react to the use of GeoGebra in the classroom?
4. What is the impact of the use of GeoGebra on the learning that took place in the classroom?

1.7 DEFINITION OF KEY TERMS

This section provides explanations of the key terms and phrases used in the previous and subsequent sections in this study.

Learner – any young person who receives education in any South African school.

Learner activities – topic-specific activities arranged in a sequence that indicates how they will be used to help learners understand the concept(s) taught by the teacher during a lesson presentation.

Levels of training – refer to Kirkpatrick's four levels, namely, reaction, learning, behaviour and results, which assist trainers to evaluate the effectiveness of training.

GeoGebra – is a free interactive software tool that is designed particularly for teaching and learning mathematics at any level of education.

Training – any logical acquisition of knowledge, concepts, skills, abilities, or attitudes that must result in improved performance of the learner or trainee.

Training evaluation– is the process of collecting data that can be used to measure learning outcomes that can be used to determine the effect of training.

1.8 RESEARCH DESIGN AND METHODOLOGY

The section below presents the research design and methodology used in this study.

1.8.1 Research design

I carried out a wide consultation of the literature on the effect of GeoGebra usage on learner achievement. Thus, this study adopted a combination of qualitative and quantitative research to understand in depth how the implementation of GeoGebra by teachers newly trained in its use influenced learner achievement. The field work in this study took place at the beginning of Term 2 in 2018 before geometry was formally taught according to the Annual Teaching Plan (ATP) designed by the Mpumalanga Provisional Education Department (MPED). The logic behind using this approach is based on the fact that the quantitative and qualitative data gathered are required for two different intentions.

The knowledge claims used in this study are based on the combination of constructivist, interpretivist and positivist assumptions (Creswell, 2013). The author further states that, on the one hand, constructivists - interpretivists believe that multiple realities exist, hence, knowledge is subjective and is constructed through interaction with the environment. This knowledge claim implies that the researcher has the freedom to interact with the participants, but must remain unbiased and select the methodology that suits the study. On the other hand, positivists claim that only one truth exists, which is objective and can only be measured using standardised instruments. The implication is that the researcher should not interfere with participants because data gathered in this way provides objective measurements.

In order to obtain answers to the main research question, the quantitative data (QUAN) took higher priority, while the quantitative data (qual) had a lower priority.

- The qualitative data (qual) was used to inform how the teachers reacted to their GeoGebra training and what changes took place in their behaviours.
- The quantitative data (QUAN) was used to evaluate how the learners reacted to GeoGebra lessons, together with how the implementation of the GeoGebra impacted their performance in the geometry achievement tests.

1.8.2 Selection of the participants

A non-probability or non-random purposive sampling (also known as judgment, selective or subjective sampling) strategy was used to select four Grade 10 mathematics teachers and their current teaching classes to take part in this study. The sample was non-random because the sample comprised one particular sub-group (teachers and their learners) in which all the sample members were similar since the schools were chosen in accordance with a list of specific criteria. Thus, the participants had similar characteristics since they all came from under-privileged rural schools with a continuous record of poor performance in mathematics in the final matric examination (Spaull & Kotze, 2015; Tsanwani et al., 2014).

1.8.3 Data collection and instruments

Both qualitative and quantitative data were collected at the same time (concurrently) in this study. The qualitative data from the teachers were gathered through a questionnaire, semi-structured interviews and class (lesson) observations. The qualitative data was used to inform *how* the newly trained teachers reacted to their GeoGebra training and also allowed me to measure the extent to which the teachers changed their behaviour. Moreover, I was interested to discover *how* they implemented their GeoGebra training in the classroom. Alternatively, the quantitative data from the learners were gathered by means of pre- and post-tests. This provided information on the extent to which learning took place and the impact of the use of GeoGebra on the learning that took place in the classroom. In addition, a questionnaire was administered and completed by the learners at the end of the learning period to inform me on *how* they felt about learning through GeoGebra.

1.8.4 Analysis and interpretation

The analysis of the qualitative data (qual) involved a content analysis of the teachers' written responses obtained from a questionnaire completed after the training, and verbal responses from interviews to provide depth on the responses gathered from the questionnaire. The aim was to identify the keys in the text that would assist in understanding how they reacted to GeoGebra training. In addition, the data collected from the class observations focusing on observable behaviours exhibited in the classroom were also analysed to inform *how* the teachers' behaviours changed as they implemented their GeoGebra training. To summarise, the steps that I took to analyse the obtained qualitative data began with manually coding responses from questionnaires, transcribed interviews and identified key indicators of teachers' changes in behaviour from the observations followed by the arrangement of data into themes, categories and sub-categories for final analysis and interpretation.

Alternatively, the quantitative data (QUAL) from the learners collected by means of pre- and post-tests and a questionnaire were analysed using data analysis software called the IBM *Statistical Package for Social Sciences* (SPSS) version 25. This software provided descriptive analysis using numbers and graphs in an attempt to understand the properties of the data, and provided inferential analysis to establish causal effects. Thus, the data gathered from the achievement tests were analysed using means or averages. This was done to understand the nature of the collected data and also to establish any causal relationship (if any) between GeoGebra instruction and learners' achievement scores in geometry. The quantitative data from the questionnaire were analysed using frequencies expressed as percentages to determine their responses, and thus their feelings about the use of GeoGebra as a learning tool.

1.8.5 Rigour

According to Bowen (2005, p. 214), when one engages in a study it is very crucial to "provide checks and balances to maintain acceptable standards of scientific inquiry by addressing the need for rigorous data collection and methods of analysis." Since this study employed a combination of qualitative and quantitative research, it is essential to discuss in brief how the rigour of the qualitative approach and the quantitative approach were enhanced. Conelley (2016, p. 435) states that "trustworthiness or rigour of a study refers to the degree of confidence in data, interpretation, and methods used to ensure the quality of a study." The requirements more appropriate for demonstrating rigour in qualitative research comprise credibility, transferability, confirmability and dependability (Conelley, 2016; Lincoln & Guba, 1994), while the requirements of reliability and validity are relevant for establishing rigor in quantitative research. Such rigour in research is evaluated by how well the study adapts to acceptable standards and whether it meets the standards for ethical conduct.

In this study, rigour in the qualitative phase was enhanced by ensuring that I used three methods for collecting data: a questionnaire, interviews and lesson observation. All the three instruments were evaluated by my supervisor and other experts before they were used. In addition, the questionnaire was pilot-tested before it was used in the main study. In the quantitative phase, reliability and validity were improved by utilising pre- and post-tests and a questionnaire that were initially evaluated by my supervisor and colleagues. Furthermore, pre- and post-tests were evaluated for content validity by the expert who provided the GeoGebra training for the teachers. Moreover, the Cronbach's Alpha for internal consistency reliability was calculated for the learner questionnaire.

A more detailed description of the research design, methodology and instruments will be provided in Chapter 3.

1.9 STRUCTURE OF THE THESIS

The thesis is structured as follows:

Chapter 2: Literature Review and theoretical framework

In this chapter, a critical evaluation of the literature around the implementation of technology to improve learner achievement in the mathematics classroom was discussed. A review of the related literature that informs the choice of the Kirkpatrick's Four-level Training Evaluation model as the theoretical framework is also presented.

Chapter 3: Research methodology and procedure

This chapter presents descriptions of the ontological and epistemological assumptions underpinning the study, the study site and settings, research design, sample size and sampling strategy. The data collection and analysis methods that constituted the design of this study are also examined. Validity, reliability and trustworthiness measures are also discussed.

Chapter 4: Results and discussion of the qualitative phase of the study

This chapter presents and discusses the research based on the qualitative data.

Chapter 5: Results and discussion of the quantitative phase of the study

This chapter presents and discusses the research based on the quantitative data.

Chapter 6: Summary, conclusions, limitations and recommendations

All the evidence from the previous chapters is synthesised in this chapter to inform the reader of what was uncovered through this study, and the limitations and recommendations are presented for future research.

1.10 CHAPTER SUMMARY

In Chapter 1, an introduction to the study was presented, followed by a description of the background of the study and a discussion of the problem that led to this research. The purpose of this study was explained, the research questions are posed, and definitions of the key words used in the subsequent sections of the study were provided. Finally, the methodological considerations were also presented and discussed in brief, while more detail is provided in Chapter 3.

CHAPTER 2 LITERATURE REVIEW AND THEORETICAL FRAMEWORK

2.1 INTRODUCTION

This chapter focuses on reviewing the literature concerned with the use of technologies as instructional tools that enhance learners` effective understanding of mathematics. This literature review begins with an overview of the role and benefits of technology integration in the mathematics classroom. The overview is followed by a discussion of in-service teachers` reactions to training and their acceptance of the use of technology in their classrooms in order to provide context to the educational program being evaluated in this study. Next, a specific review of the literature regarding the use of GeoGebra as an ICT option for teaching geometry and how it has influenced the performance of learners in mathematics is provided. Literature regarding Kirkpatrick's Four-Level Training Evaluation model as the theoretical framework that directed this study within a GeoGebra environment including its limitations is also discussed followed by a summary of the chapter.

2.2 TECHNOLOGY IN THE MATHEMATICS CLASSROOM

The demand for and the use of technology in the mathematics classroom have increased due to the rapid growth of educational technologies that can support effective instructional practices (Gerrit Stols & Kriek, 2011; Muhannad, Munim & Al-Labadi, 2017; Yılmaz Zengin & Tatar, 2017). The introduction of Information and Communications Technology (ICT) activities encourages a collaborative learning environment that directs the process of teaching and learning towards learner-centred instruction. Learners are afforded opportunities to construct their own knowledge, while technology allows them to remain engaged and active in the whole learning process (Denbel, 2014; Leong, 2013; Tatar, 2013). Individualised and adjustable learning experiences offered by the inclusion of ICT enable learners to focus on relevant self-driven learning needs, unlike in a rigid teacher-centred environment.

In a technology-driven environment, learners are provided with an opportunity to take control of their learning processes when they interact with technology, increasing their chances of improving their academic performance (Bozalek, Ng'ambi & Gachago, 2013). Consequently, the use of ICTs in a mathematics classroom has the potential to create an atmosphere that enhances the interaction between learners and the concepts they learn (Bhagat & Chang, 2015). Technology integration provides learners with the chance to see patterns, manipulate dynamic images, and learn from instant and accurate feedback in order to realise the connections between abstract concepts and practise through explorations. In addition, ICT as a tool for instruction allows learners to share mathematical ideas within the classroom, resulting in improved learning outcomes (Voogt, Knezek, Cox, Knezek & Ten Brummelhuis, 2013).

Although Bansilal (2015) reports that most researchers agree that technologies could enhance the learning and understanding of various mathematical ideas, Chigona et al. (2014) have found that the use of technology can produce undesired results such as: a) A failure to finish the curriculum content because of increased lesson preparation time when teaching with technology, b) Teaching computers instead of teaching with computers, c) Wasting teaching time during lessons when teachers find themselves assisting learners who lack basic computer skills instead of delivering curriculum content, and d) Using technology as a procedural tool instead of a pedagogical tool. All the above problems will impact negatively on teaching and learning in the classroom.

2.2.1 Technology and the mathematics curriculum

The way of teaching and learning mathematics has substantially changed due to the introduction of technology. In recent years, we have seen a drastic increase in technology sources meant to enhance teaching and learning ranging from abacuses introduced many years ago to the most recent ones. Thus, new technologies are constantly being introduced, encouraging teachers to find more ways to integrate these technologies into the classroom in order to enhance teaching and learning. These technologies include, but are not limited to: calculators, graphing scientific calculators, whiteboards, smartboards, computers, IPads, IPods, tablets, smartphones, smart watches, mathematical software such GeoGebra, Cabri, Geometer Sketch Pad (GSP) and so forth (Borba et al., 2017; Roschelle et al., 2010; Subramanian, 2018). Technology offers several benefits associated with its use in a mathematics classroom such as making teaching and learning interesting and more useful for developing conceptual understanding, and providing a deeper approach to learning (Subramanian, 2018).

In terms of pedagogy, Ruthven (2009) and Bingimlas (2009) claim that technology has the potential to facilitate active methods of learning by allowing learners to discover and construct their own knowledge, hence enhancing their capabilities in understanding basic mathematical concepts. These technological tools allow learners to gather information, and use it for mathematical purposes (Subramanian, 2018). The use of technology thus helps learners to get involved as they attempt to access information that may not be readily available from their teachers, improving their confidence and individualised learning (Borba et al., 2017; Murphy, 2016). This has been widely accepted globally for teaching mathematics in current times. Roschelle et al. (2010) explain, “In particular, technology can support mathematical ideas in ways that are important for conceptual understanding” (p. 837). According to Hegedus, Dalton, and Tapper (2015), technology increases learner engagement and learners’ conceptual knowledge.

Gilakjani and Leong (2012) explain that the unique opportunities offered by technologies have brought about new tools, approaches, and strategies for enhancing mathematics skills in learners. So, it is very important for mathematics teachers to be aware of and have full knowledge of the latest technologies. According to Alagic (2003), technology enables users to learn because some technologies are interactive in nature, such as GeoGebra, Calibri, and GSP to name a few. These interactive technologies allow the user the opportunity to observe changes immediately when mathematical computations and manipulations are done. It should be mentioned that new technologies are constantly developed and become widely spread, thus one cannot overlook their influence on the teaching and learning of mathematics (Shyamlee, 2012). However, Ghavifekr and Rosdy (2015) insist that computers and technology are not meant to replace teachers but to be taken as supplements required for better mathematics teaching and learning. It is therefore encouraged that schools provide access to computers, mathematical software, the internet, and other instructional technologies.

Due to the educational benefits afforded by technology, the South African government went through radical curriculum reforms which saw the introduction of the e-Education policy, among other curriculum changes in the schools (DOE, 2004). This policy was introduced with the aim of changing learning and teaching, according to Vandeyar (2015), by way of connecting learners and teachers to better information and ideas through effective combinations of pedagogy and technology. The Department of Basic Education (DBE) introduced the most recent Curriculum and Assessment Policy Statement (CAPS) document for mathematics in 2012 (Olivier, 2014). The DBE, through its CAPS mathematics curriculum, emphasises the use of any available technology for the benefit of the learners in the classroom, which corresponds with the policy document on e-Education (DoE, 2004). Nevertheless, schools’ readiness for

ICT integration is still in the early stages (Dutta, Geiger & Lanvin, 2015; Vandeyar, 2013, 2015). Although the CAPS document urges teachers to make use of technology in class, little to no training and proper planning has been given to rural teachers from most rural (quintiles 1-3) schools on the effective use of technology integration in their instruction (Howie & Blignaut, 2009; Martinez, 2017; Nkula & Krauss, 2014).

Thus, a gap still exists between the requirements and recommendations of the e-Education policy document by the DoE (2004) and classroom practice. However, in most quintile 4 and 5 schools in South Africa, teaching and learning with technology is not something new. Most of these schools (Chigona, 2011; Naidoo, 2012; Tire & Mlitwa, 2008) have attempted to integrate technology since they have been equipped by the government with computer laboratories that provide learners with access to computers. However, the challenge of effective technology usage is still prevalent in rural schools. As a result, more focus directed towards training and motivating teachers from rural schools in all South African provinces is required. Mainali and Key (2008) indicate that the effective and easy use of Dynamic Geometry Software (DGS) like GeoGebra by teachers requires workshops directed at providing constant training on its use to boost their confidence. This need for regular training and workshops is also confirmed by Bansilal (2015).

2.2.2 Technology in rural schools

Although technology has been incorporated into many urban schools, unfortunately, the same cannot be assumed about their counterparts situated in rural areas (Mahdrum, Handriana & Safriyanti, 2019; Nwangwu, Obi & Ogwu, 2014). In spite of the identified benefits, such as increased learner engagement, academic performance, motivation, amongst other, by Delen and Bulut (2011) and Gilakjani (2017), rural schools have huge challenges with regard to the issue of incorporating technology into their classrooms. In practice, the usual mathematics teaching and curriculum approaches still remain essentially unaltered in many South African schools in the rural areas and a few urban schools, regardless of the existence of several modern educational technologies (Dzansi & Amedzo, 2014). In few cases where technology is available, it is normally poorly implemented and underutilised in the classroom (Chigona & Chigona, 2010; Dzansi & Amedzo, 2014). Problem(s) relating to technology integration in schools, especially in under-resourced schools in rural areas, may result in a widened gap in terms of access to ICTs between learners in urban areas and rural areas (Dzansi & Amedzo, 2014; Ghavifekr et al., 2014). Despite its importance and the approaches formulated by government to implement technology in schools, a majority of rural schools in the country are not effectively adopting and using technology to support learning and teaching as intended (Chepkorir & Kandiri, 2018).

Besides the challenges discussed in the previous sections that are directly linked to teachers as inhibitors of technology integration, other challenges associated with the use of technology in rural schools may be related to policy, management and administration by schools, districts or provinces (Padayachee, 2017; Vandeyar, 2010, 2013, 2015). For example, notwithstanding the South African government`s initiatives to increase the use of educational technology in all schools, its implementation in most rural schools has not been fully achieved yet. Even though the e-Education policy document and the execution plan exists, the DBE’s ability to perform is inadequate and the implementation process is very slow, more so in many schools in rural areas (Vandeyar, 2015). There is no systematic plan of action across the whole education system. The practical implementation of e-education is characterised by objectives that are not clear (Padayachee & Mbati, 2016). Access to technology is limited and uneven across provinces, districts and schools. In the absence of clear objectives, the practical enforcement of the e-Education policy, and integrative schemes’ progress is negatively affected (Padayachee, 2017; Vandeyar, 2015).

Furthermore, many rural schools, unlike urban schools, have not embraced technology mainly because of a lack of resources and facilities, and a lack of adequate training on the use of technologies that enhance teaching and learning (Chigona & Chigona, 2010; Dzansi & Amedzo, 2014; Wachiuri, 2015). For instance, even if marginalised rural schools happen to have computers mostly obtained from parastatals, private sector and donor agencies, very few teachers are able to use these to improve teaching and learning. In many cases, any computers they receive end up being used for administrative work and not for instruction (Ndlovu & Lawence, 2012). While the integration of technologies into the classroom is recommended for 21st century learning, many learners, especially in rural school settings, are not privileged to receive that kind of education in South Africa. Although the use of technology has become an important part of the learning process, special educational facilities such as computer labs are either lacking or dysfunctional in some rural schools (Dzansi & Amedzo, 2014). In addition, most rural schools still struggle with providing adequate classroom buildings to fit all their learners, while others battle with basic services like electricity, sanitation and tap water (Msila, 2015; Padayachee, 2017).

The limited usage of ICT for instructional purposes in many under-privileged rural schools in South Africa had several implications for this study. The constraints under which the use of technology in rural schools is implemented are essential in assisting to identify the training needs that are relevant for rural schools in South Africa. As a result of the limited ICT use owing to lack of in-service teacher training, the intended training in the use of GeoGebra in teaching geometry is likely to be seen by teachers as a new and valuable pedagogical approach. Hence, in this study, it was important to evaluate newly trained teachers' reactions towards the use of GeoGebra and change in behaviour towards their intended practice. Furthermore, it was vital to investigate how teachers' implementation influenced the performance of learners, and to explore further how learners felt about learning with GeoGebra.

2.2.3 Integrating ICT into Euclidean geometry teaching and learning

Since geometry is the study of space and shapes, various representations can be used to teach it, such as diagrams, graphs, and drawings, amongst others. However, enhanced learning of geometric concepts can be facilitated by including ICTs with dynamic features for instructional purposes such as GeoGebra, GSP, Cabri, Cinderella and many more. In pencil and paper constructions, the results of a complete construction process remain stationary, although the process of doing constructions comes from mental manipulations. Computer technology therefore facilitates learners' development of abstract geometrical concepts because it provides multiple representations of concepts while allowing learners to drag, animate, visualise and investigate different properties of geometric shapes (Arbain & Shukor, 2015; Haciomeroglu & Andreasen, 2013; Shadaan & Leong, 2013). In addition, ICT-driven instruction provides a much needed visual description of a complete dynamic process, which assists learners to construct meaningful concepts in geometry.

In contrast, textbook-based geometric diagrams only allow learners to see static (non-moving) geometric pictures, forcing them to create geometrical constructions mentally through imagination, leading to rote learning. Nonetheless, the process of incorporating ICT into Euclidean geometry lessons has to be done at both pedagogical and technological levels with more emphasis put on pedagogy. It must be clearly stated that the use of mathematical software does not always ensure that the outcome is favourable, but the way in which the software is used has an influence on shaping the desired results (Mishra & Koehler, 2006; Nkula & Krauss, 2014). In other words, the integration of ICTs into classroom activities creates more relevant and engaged teaching and learning environments, and when used properly, it can increase learners' performance.

In summary, ICT and pedagogy can be consistently merged in a more significant way in the mathematics classroom to ensure that learners interact in order to address their individual needs, which enhances their conceptual understanding of geometric concepts. GeoGebra instruction software makes lessons more exciting, motivating, hands-on and easy to understand (Bhagat & Chang, 2015; Bist, 2017; Boo, 2016). The GeoGebra-enhanced environment encourages learners to interact, discuss relevant mathematical content in various topics and learn from one another.

2.3 Teachers' reactions to training

The literature on training has revealed that with suitable conditions, training has the potential to meaningfully change teachers' behaviour, beliefs and attitudes, knowledge, classroom practice and their learners` performance (Ramatlapana, 2009). She goes on to say that the aim of in-service training is "to improve the quality of teaching by supporting teachers through training programmes that enable them to take ownership of their professional development" (p. 153). Hence, in-service training is relevant to this study because the intention is to investigate how the implementation of GeoGebra training by teachers newly-trained in its use influences their classroom practice. This study also explored the impact of this implementation on learner experience and achievement. According to Zulkifli (2014), the in-service training of a teacher is the sum total of the individual and educational experiences that contribute to someone being more competent and satisfied in an assigned professional role. Due to an increasing attention on in-service teachers` training programmes, it is important to find out what past studies have said about their reactions to training (Zulkifli, 2014). Kirkpatrick (1998) perceives training to embrace professional growth, and states that training programmes are "designed to increase knowledge, improve skills, and change attitudes" (p. xvi).

In light of the above, the success or failure of all training programmes is hinged on how trainees react to the training. For instance, teachers' reactions towards the integration of technology into the curriculum play a crucial role in the teaching and learning process, especially when it comes to positive attitudes. Teachers who show positive attitudes towards technology can be successful in its integration into the mathematics curriculum, and in their classroom practices (Barakabitze, 2014). Previous evaluation studies of in-service teacher training show positive changes in the teachers' attitudes, knowledge and classroom practices, although most of them focused on learning satisfaction due to time constraints (Sánchez, Marcos, González & GuanLin, 2012). In some international studies, the teachers were found to react positively to their training on how to integrate technology into their curricula. They were generally satisfied with their training, showing a positive impact in the assessment of their reaction (Ahmadi & Keshavarzi, 2013; Gorghiu, Gorghiu, Dumitrescu, Olteanu & Glava, 2011; Hue & Jalil, 2013; İzci, 2016; Panagiotis, Adamantios, Efthymios & Adamos, 2011; Shek & Chak, 2012). However, some of the teachers pointed out that some training programmes did not meet the their needs, showing evidence of the programmes' weaknesses (Hue & Jalil, 2013; Shek & Chak, 2012).

Sedega, Mishiwo, and Seddoh, (2019) have found that most of the teachers in their study perceived in-service training programmes as adequate and very effective, even though their Head Teachers dismissed their claims. For instance, teachers who participated in a study conducted by Panagiotis, Adamantios, Efthymios, and Adamos (2011) were positive about the benefits of continued training, even though the majority of them were not fully satisfied with the training they received. These findings are consistent with other international studies (Hue & Jalil, 2013; Yusoff et al., 2016). Overall, the findings from the consulted literature show that in-service training performed by different schools or colleges for teachers garnered positive reactions by the participants. This implies that if in-service teachers are exposed to properly planned training programmes on the use of technologies in the classrooms, their attitudes towards technology integration could be improved. However, undesirable results may arise in cases where teachers are not properly trained (Khokhar et al., 2017).

2.4 Teachers' acceptance of the use of technology in their classrooms

The teaching and use of technology in schools require teachers who are technologically knowledgeable and enthusiastic about its use, and thus accept its relevance to instruction. The intention of a user to use a certain system is strongly influenced by the perceived usefulness of the technology, perceived ease of use, attitudes towards using, and behavioural intention to use

(Davis, 1989; Ghavifekr & Rosdy, 2015). Perceived usefulness shapes the user`s acceptance of using a certain system, which is believed to boost their performances (Davis et al., 1989). These teachers know the benefits of technology for both themselves and the learners. When teachers believe that using a certain type of technological tool can improve their performance, they are bound to use it (Lai, 2017).

Teachers may feel that they can enhance their performance in teaching if they use technology. This stimulates their enthusiasm to accept using technology in teaching. Perceived ease of use determines the extent to which a user expects the application to be used without a lot of effort (Davis, 1989). Singhavi, Basargekar, and Somaiya (2019) mention that while accepting the important role played by ICT in education is vital, its implementation in the classroom faces huge challenges. Previous studies show that problems related to the use a particular technology may come from technical and non-technical factors (Shafeeq & Baskaran, 2015; Singhavi et al., 2019; Uslu, 2018). In technical terms, teachers' acceptance or rejection of technology may be related to a lack of electricity, little or no access to the internet, the unavailability of essential facilities and so forth (Bingimlas, 2009; Msila, 2015; Sundeen & Sundeen, 2013).

On the contrary, the fact that teachers may also feel reluctant to use technology is because of their inability to use computers, a lack of training in the use of technology, or feeling that the instructional approach in teaching is not suitable for them (Bingimlas, 2009; Mou, 2019; Msila, 2015; Salam, Zeng, Pathan, Latif & Shaheen, 2018; Singhavi et al., 2019). These environments cause teachers to believe that using technology requires a lot of effort and hence their motivation towards its implementation decreases. Additionally, attitude towards using a target system is explained as the user's evaluation of the benefit of using a particular information system in the classroom (Sang, Valcke, Braak & Tondeur, 2009). This relates to users' feelings towards the use of a particular technology (Amuko, Miheso & Ndeuthi, 2015). When a teacher feels positively about technology in teaching and learning, he/she may use it. When a teacher feels negatively towards technology, he/she may avoid using it (Bingimlas, 2009). In other words, once a person lacks a favourable attitude towards technology, the likelihood of actually employing such technology in the classroom decreases significantly (Wahbeh, Sagher, Back, Pundhir & Travis, 2018).

2.5 ICT OPTIONS FOR TEACHING GEOMETRY

There are high expectations from educational scholars for ICT usage in improving the teaching and learning of school geometry internationally (Sinclair et al., 2017). In recent years, there has been growing attention on the importance of rising new technologies, leading to new challenges in the use of technology in a geometry classroom, although their role in teaching and learning is still not clearly understood. While technology in geometry education has become somewhat normal, there is still limited research into its particular effects (Jones, 2011). Since the early 1990s, over 40 different Dynamic Geometry Software (DGS) programs for geometry have been developed and made available for free, while others require a commercial licence for their use in various countries. These include: Geometer Sketchpad (GSP), Cabri Geometre, Thales, Geometry Inventor and GeoGebra, to name a few (Sinclair et al., 2017).

Although these DGS programs are different, they share common features. These features include: a set of primitive objects according to Oldknow (1997), such as points, straight objects such as lines, segments and rays, and arcs or circles (Oldknow, 1997). From these features, users are able to use various built-in tools to construct perpendicular and parallel lines, perform transformations and calculations, measure, animate, hide objects, and create procedures. These geometric packages have been introduced in most schools from both developed and developing countries, for example, South Africa, to improve the teaching and learning of mathematics (and geometry in particular) (Wilson-Strydom, Thomson & Hodgkinson-Williams, 2005). This is due to fact that they change the representations of geometric shapes reasonably well, as compared to static paper-and-pencil methods. In spite of the fact that these DGS software programs may not be used to solve a task, their role in the classroom is to assist learners to visualise and make conjectures about the relations using the drag mode in order to understand the situation under investigation (Jones, 2011; Sinclair et al., 2017)

The next section focuses on free interactive geometry software called GeoGebra as an ICT option for teaching geometry. The central theme in this section is what the literature says about GeoGebra’s visualisation and manipulation or dragging features, which makes it relevant software for the teaching and learning of geometry, specifically in terms of triangles and quadrilaterals.

2.6 GeoGebra as an ICT option for teaching geometry

GeoGebra is classified as one of several ICT tools in current use among other relevant programs that can be used to teach geometry, such as Cabri Geometer's Sketchpad (GSP), Geometry Inventor, Cinderella, and Thales (Boo, 2016; Oldknow, 1997). Since internet connection is not a prerequisite for using GeoGebra, it was considered a better option for schools in the rural areas where connection to the internet continues to be problematic, if not non-existent, in South Africa. GeoGebra as an interactive software has the potential to encourage a shift from the common traditional teaching methods when teaching geometry to more effective learner-centred methods that may promote enhanced teaching and learning in the classroom. Although GeoGebra as a tool for effective instruction has been used in various mathematics topics such as statistics, algebra, trigonometry, calculus and others, its benefits have been extended to geometry (Amam, Fatimah, Hartono & Effendi, 2017; Hohenwarter, 2017).

GeoGebra as a free and user-friendly software has been introduced in most geometry lessons because of its features and properties that allow learners and teachers to explore the properties of geometric shapes while visualising the effects at the same time. Visualisation helps to: a) Promote visual reasoning in poorly achieving learners, increasing their knowledge skills (Moyer-Packenham, Ulmer & Anderson, 2012); b) Foster the cognitive processes associated with dynamic visualisations (Dockendorff & Solar, 2018; Naidoo, 2012), and c) Observe, explore and predict the theorems and properties of geometric shapes, forming a strong base for abstract geometric proofs at higher levels of learning.

This software can also be used to change the orientation of geometric figures by using the dragging option tools, which is not attainable on paper (Shadaan & Leong, 2013). The dragging property of GeoGebra enables manipulations involving the properties of geometric shapes, allowing users to observe, explore, predict, explain, and make conjectures about the relationships between geometric figures like triangles and quadrilaterals (Zengin, Furkan & Kutluca, 2012). Hence, the dragging effect encourages learners to develop visual thinking skills as they make connections between what they see in dynamic motion and abstract geometrical concepts compared to the static motion offered by shapes drawn on paper (Dikovic, 2009). Furthermore, it provides instant, visible feedback on visual manipulations that are easy to interpret as compared to the static representations offered by paper and pencil methods. Learners' actions and reactions receive instant feedback throughout the learning process.

Consequently, the learning of geometry through GeoGebra becomes fun as learners interact directly with the algebra and dynamic windows. According to Caglayan (2015), GeoGebra's dynamic nature is important to this approach given its "ability to visually make explicit the implicit dynamism of thinking about mathematical, in particular geometrical, concepts" (p. 197). In that respect, GeoGebra is regarded as a powerful free pedagogical tool that can be used to improve the quality of the teaching and learning of numerous mathematics topics, including geometry (Thohirudin, Maryati & Dwirahayu, 2016). Numerous studies have recommended the usefulness of GeoGebra in supporting and transforming the teaching and learning of mathematics (Azizul, Miftahul, Saidatuna & Din, 2016; Saha, Ayub & Tarmizi, 2010).

Despite the positive findings from the literature, a few studies (Çiftci & Tatar, 2014; DemİrbİIek & Özkale, 2014; Dogan & Icel, 2011; Saha et al., 2010) indicate that either GeoGebra had no impact or the impact was not significantly positive in the group exposed to the intervention. For example, Saha et al. (2010) did a study involving a comparison between learners with high visual-spatial ability (HV) and learners with low visual-spatial ability (LV). The results indicated that the performance between the HV group taught without GeoGebra and the HV group taught with GeoGebra did not show significant differences. The literature in the next section provides evidence of the effectiveness of GeoGebra as a tool used to enhance classroom instruction.

2.7 THE USE AND EFFECT OF GEOGEBRA IN THE MATHEMATICS CLASSROOM

The use of GeoGebra as a tool of instruction in mathematics and its influence on the achievement gains of learners has attracted a lot of attention locally and globally (Shadaan & Leong, 2013). However, to date, very little research has been conducted in South Africa regarding this topic. In recent years, there has been an increase in the number of people who use it as instructional strategy in the classroom (Poon, 2018). In the interest of investigating how GeoGebra software usage in the classroom influences learners' achievement, the literature describing past studies in this respect was reviewed. These [past studies] advise that GeoGebra has a huge potential to allow discovery learning in different topics in mathematics, for example, trigonometry (Yilmaz Zengin, Furkan & Kutluca, 2012), calculus (Dikovic, 2009), fractions (Bulut, Akçakın, Kaya & Akçakın, 2016; Thambi & Leong, 2013), coordinate geometry (Saha et al., 2010), functions (Zulnaidi & Zakaria, 2012) and many others.

Haciomeroglu and Andreasen (2013) discovered that GeoGebra helps learners to improve their understanding, resulting in higher marks in calculus. Another study done in Turkey by Zengin et al. (2012) suggests that learners who were taught with GeoGebra ($M = 72.39, SD = 12.51$) obtained better results compared to the control group ($M = 54.09, SD = 9.83$) at 0.05 level of significance (t_{51} = 5.43, $p <$ .001). They also revealed that learners who learnt through GeoGebra became positive, interested and enjoyed the learning environment. The above results are consistent with a study conducted by Lalduhawma (2015) in India.

Lalduhawma (2015) examined the effect of GeoGebra on learners' motivation and interest. His study showed that learners who participated in a training programme involving GeoGebra usage in a mathematics class got excited and were willing to participate in further training and workshops. Studies done in Turkey to evaluate the impact of GeoGebra on learning fractions revealed that primary school learners achieved better results using GeoGebra as compared to learners who received tuition in the traditional teaching method (Bulut et al., 2016; Thambi & Leong, 2013). In another study in Indonesia, Zulnaidi and Zamri (2017) investigated the impact of GeoGebra instruction in Form Two learners' conceptual, procedural knowledge and achievement in the topic of functions. Overall, the findings from their study indicate that GeoGebra has the ability to increase the conceptual and procedural knowledge of learners, resulting in significant improvement in learners' achievement. Zulnaidi and Zakaria (2012) obtained similar findings in their study.

Several other studies investigating the effectiveness of using DGS (GeoGebra) have been carried out on learners' understanding of basic geometric concepts and academic achievement (Bakar, Ayub & Mahmud, 2015; Bhagat & Chang, 2015; Çakir, Gezgin & Özkan, 2017; Denbel, 2015; Saha et al., 2010; Seloraji & Leong, 2017; Shadaan & Leong, 2013; Turk & Akyuz, 2015). For instance, Bakar *et al*. (2015) investigated the impact of using GeoGebra on learners' mathematics performance in a Malaysian secondary school, as compared to traditional instruction. The results from post-test marks indicated that the learners taught with GeoGebra achieved higher marks as compared to the group where GeoGebra was not used for teaching.

Bhagat and Chang (2015) did a similar study on integrating GeoGebra into the learning of geometry in India. Their aim was to study the impact of GeoGebra usage on Grade 9 learners' academic success. GeoGebra was found to have some positive effect on the performance of the learners. In another study conducted in Turkey by Özçakır et al. (2015), it was found that teaching triangle-based activities with GeoGebra instruction increased the academic performance of the eighth grade learners. In other words, their academic performance was raised (M = 72) as compared to learners in the traditional instruction group (M = 59.67). Kushwaha, Chaurasia and Singhal (2014) also found similar results to those found by Bakar et al. (2015), Bhagat and Chang (2015) and Özçakır et al. (2015). Their study was aimed at investigating how GeoGebra impacted learners' achievement in a secondary school in India.

The above findings are consistent with Dogan and Icel (2011), who examined the role of GeoGebra when teaching about triangles. They established that the differences between the groups were statistically significant for the two tests written after receiving the treatment. The treatment group was more successful (M = 63,15 and M =74,75) than the control group (M = 42,45 and M = 54,45) in both tests, indicating that GeoGebra significantly increased learners' success. Taken as a whole, the results of these studies show that the use of GeoGebra results in a significant increase in learners' success and understanding of basic concepts in geometry. All of the above studies stress the point that teachers should promote GeoGebra usage because it provides a learning environment that encourages learners to remain engaged while raising their motivation towards learning mathematics at the same time.

Alternatively, Masri et al. (2016) conducted a case study involving a Malaysian secondary school. Their study examined the effects of using GeoGebra in learning the geometry of circles focusing on the relationship between angles and tangents in terms of Form 4 learners' performance and attitudes towards this teaching strategy. The analysis from a samples t-test and ANCOVA did not identify any significant differences between the mean performance scores of the experimental (M = 49.49) and the control (M = 33.41) groups at a 0.05 significance level. In spite of the fact that the results showed that a significant relationship existed between the pre- and post-tests, it was found that the teaching method had no significant influence on the post-test scores. Masri et al. (2016), Dogan and Icel (2011) and Mustafa (2014) also argue that GeoGebra-supported instruction is effective, and they point out that the effectiveness of GeoGebra in terms of the academic success of learners may be different from that suggested by a number of authors (Bakar et al., 2015; Bhagat & Chang, 2015; Çakir et al., 2017; Denbel, 2015; Saha et al., 2010; Seloraji & Leong, 2017; Shadaan & Leong, 2013; Turk & Akyuz, 2015). The results from their studies showed that GeoGebra had little effect or did not have a positive effect on learners' academic achievement, particularly that of poor achievers.

A study by Gweshe and Dhlamini (2015) looked into how the motivation and performance of learners in circle geometry are influenced by the use of Computer-Assisted Instruction (CAI). The study consisted of Grade 11 learners from a district in the Gauteng province. The results of their study showed that GeoGebra usage had a positive impact because learners` achievement and motivation were significantly improved. Similar results were found in a case study by Naidoo and Govender (2014), whose aim was to explore the use of dynamic online GeoGebra software when teaching trigonometric graphs to a group of Grade 10 learners. Their findings demonstrated that learners became motivated and produced an average mark of 18.16 with an overall performance of 91% on worksheet questions that they completed online, showing a significant improvement in the marks of the learners. The implication of their results is that GeoGebra is an effective platform that provides learners with opportunities to develop visual, critical and higher-order thinking skills.

Some studies utilised other educational technologies in investigating their impact on the performance of learners in geometry topics. Ngonyofi and Ndeukumwa (2017) planned to determine the possible effects of Geometer’s Sketch Pad (DSP) on learner achievement in geometry-related topics in a Namibian school. Their study, which consisted of Grade 12 learners, revealed that learners taught using DSP out-performed learners exposed to the traditional teaching method. Separate studies by Dimakos and Zaranis (2010), Idris (2009) and Kesan and Caliscan (2013) also recommended the incorporation of GSP as a powerful tool for instruction in geometry lessons.

Overall, the results from all the above studies demonstrate that DGS pedagogy can improve the performance of learners as compared to the conventional method, more so when users become motivated (Gweshe & Dhlamini, 2015). This implies that teachers need to take advantage of teaching geometry with GeoGebra for the development of learners’ skills of visual thinking, which go beyond observation and academic achievement. The DGS can present concepts on properties of geometric figures in an exciting, satisfying and interesting way through its use of colours, drawings and movement, which in turn attracts learners to learning geometry. Consequently, GeoGebra-supported teaching methods are recommended in the classroom because they motivate learners to learn and eventually promote an increase in their academic marks. GeoGebra can enhance learners' effective understanding of geometrical concepts, hence it has a positive impact on mathematics education (Hohenwarter & Jones, 2007). Hohenwarter, then a student at the University of Salzburg in Austria, created the GeoGebra software in his Master's dissertation in 2002. The GeoGebra software clearly links algebra and geometry (Martinez, 2017).

Many studies have recommended GeoGebra as a useful tool in several different ways in mathematics education. For instance, Hohenwarter and Fuchs (2005) identified the following ways in which GeoGebra can be of use in the classroom: "1) for demonstration and visualisation; 2) as a construction tool; 3) as a tool for discovering mathematics; 4) as a tool for preparing teaching materials" (p. 3). Despite the positive results discussed in the literature (Freiman, Martinovic & Karadag, 2010; Little, 2008) on the use of GeoGebra, Freiman et al. (2010) and Dikovi (2009) state that there is still a need to investigate its use as a pedagogical tool in the classroom. Much literature has focused on pre-service teachers and/or learners` perceptions of GeoGebra usage (Bansilal, 2015; Stols, 2015), learner achievement, and motivation (Chigona et al., 2014; Gweshe & Dhlamini, 2015; Naidoo & Govender, 2014). Guided by these recommendations, it is important to conduct similar studies in the South African context focusing more specifically on how the use of GeoGebra can change learner achievement when implemented in the classroom by teachers newly trained in its use.

2.8 THEORETICAL FRAMEWORKS USED IN MATHEMATICS EDUCATION

In this section, the different theoretical frameworks used as lenses for guiding researchers when investigating the teaching and learning of geometry in the past, including those that support the successful intergration of technologies, are discussed. Detail is presented on Kirkpatrick's Four-level Training Evaluation Model as the theoretical framework that informed the current study.

2.8.1 An overview of the relevant theoretical frameworks

Many researchers have developed frameworks in an attempt to understand how learners learn and develop a deep understanding of geometric concepts (Vojkuvkova, 2012: Kutluca, 2013). These frameworks include, for example, the Van Hiele model of geometric understanding, Fischbein's Theory of Figural Concepts, and Duval's cognitive model of geometrical reasoning. Other theoretical frameworks deal with human behaviour in the context of technology use in education, such as the Technology Acceptance Model (TAM), the Theory of Planned Behaviour (TPB), the Theory of Reasoned Action (TRA), and the Innovation Diffusion Theory (IDT) (Alraja, 2015). The four theories, namely, TAM, TPB, TRA and IDT identified above have been used to predict and explain how human behaviour changes as teaching and learning with technology takes place (Alraja, 2015; Arpaci, 2016, 2017; Hillar, 2014; Park & Kim, 2014; Park & Ryoo, 2013; Sabi, Uzoka, Langmia & Njeh, 2016; Sharma, Al-Badi, Govindaluri & Al-Kharusi, 2016; Shiau & Chau, 2016; Stols & Kriek, 2011).

Although various studies on technology integration in the mathematics curriculum have been widely condemned for their lack of theoretical or conceptual coherence, they have continued to be used in various studies. Critics have argued that most of these studies are of poor quality, with little or no evidence of their contribution to the body of knowledge (Demir, 2011; Sackstein & Slonimsky, 2017). In spite of that, numerous frameworks, some specific to technology while others more general, have been developed and used in various studies specific to geometry or mathematics in general. In some studies, two or more theoretical/conceptual frameworks are merged to indicate that the technology component cannot be a stand-alone domain. However, the literature consulted on the use of GeoGebra focuses mainly on aspects such as participants' perceptions, attitudes and/or how GeoGebra influences learner achievement. Training evaluation was not considered and, as such, has remained a grey area in research (Heydari, Taghva, Amini & Delavari, 2019).

Heydari, Taghva, Amini and Delavari (2019) state that "training is a useful investment and is one of the most important factors in human resource development" (p. 1). They further indicate that if the training is properly conducted, it can improve participants' satisfaction, as well as the intended results. As a result, this study used Kirkpatrick's programme evaluation framework to evaluate the effect of GeoGebra training on participants' satisfaction, learning, and change in their behaviour. Hence, the model, originally developed and published by Kirkpatrick in 1959, was used to evaluate the training involving this new teaching and learning method. This is discussed in detail in the next section.

2.8.2 Kirkpatrick's Four-level Framework for training programme evaluation

This study adopted Kirkpatrick's four-level model of training evaluation as the theoretical framework. There are various frameworks and models for measuring and evaluating training programmes. However, the most recognised framework is Kirkpatrick's Four-level evaluation model. This model is one of the most well-known and commonly used methods to evaluate the effectiveness of training programmes, and to examine the impact of and results from both individual and organisational perspectives (Rafiq, 2015). The logical four-level training evaluation model has been in existence for over 50 years now. Kirkpatrick's Four-Level Training Evaluation Model has gained enormous, worldwide support over time as one of the mostly accepted and influential frameworks for training evaluation (Aziz, 2016; Dorri, Akbari & Sedeh, 2017; Fardaniah & Aziz, 2013). Moreover, Kirkpatrick's framework has been considered as the most popular and standardised framework for evaluating training programmes (Bates, 2004; Holton, 1996; Rajeev, Madan, & Jayarajan, 2009).

According to the four levels of training espoused by this model (Kirkpatrick & Kirkpatrick, 2010), training should be analysed and evaluated using four sequentially ordered and interrelated learning levels, namely: 1) Reaction, 2) Learning, 3) Behaviour, and 4) Results (Kirkpatrick, 1996; Kirkpatrick & Kirkpatrick, 2010). I used only the first three levels because those were the levels considered relevant to this study. Level 4 was not used since the study mainly focused on how the implementation of GeoGebra by teachers newly trained in its use influenced the performance of learners. Kirkpatrick's framework was found to be appropriate in this study because it was developed to examine more real measures of impact rather than merely measuring the reactions or feelings of the participants. This approach is supported by Joyce and Showers (1980), who report that "to be most effective, training should include theory, demonstration, practice, feedback, and classroom application" (p. 379).

Consequently, Kirkpatrick's model was used to show that effective training can allow for new strategies that may result in a positive change in teachers' views, learning, and behaviours. Meaningful learning may take place when there is a positive change in the attitudes of the participants who have received some training that they consider relevant to their jobs (Heydari et al., 2019; Kirkpatrick & Kirkpatrick, 2010; Shawer, 2018; Smidt, Balandin, Sigafoos & Reed, 2009; Zala-Mezö, Raeder & Strauss, 2019). However, Kirkpatrick (1959, 1996) reports that evaluation becomes more difficult and valuable as one moves from levels 1 to 4, even though the evaluation becomes more significant.

Figure 2.1 below depicts the four learning levels, while their detailed descriptions are provided in the subsequent section.

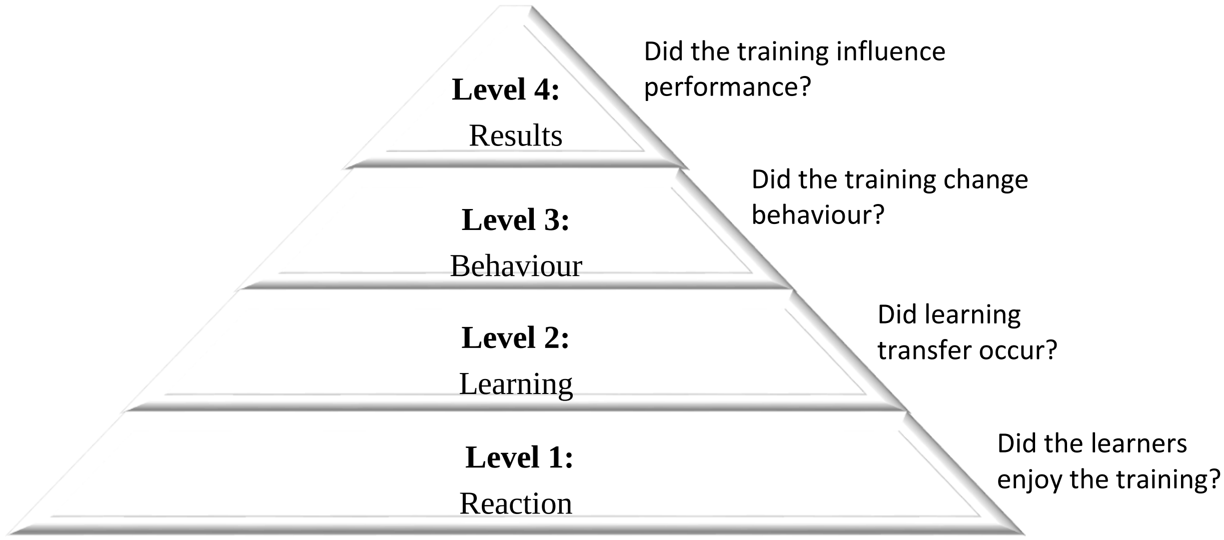

Figure 2.1: The four-level Training Evaluation Model (Kirkpatrick, 1996)

The four levels of training evaluation depicted in Figure 2.1 are discussed in detail below.

Level 1: Evaluating reaction

At this level, the main focus is on the evaluation of learners' perceptions (reactions) or how they feel about the program and its effectiveness. As such, reaction may be defined as how well learners like the instruction and training material used, or parts thereof. According to Dorri et al. (2017), " Reaction is the act that learners demonstrate to all effective factors during a training period" (p. 494). Measuring how learners were engaged, how actively they contributed, and how they reacted to the training helps one to understand how well they received it. The instruments used for measuring reactions usually requests comments about the training content, materials, facilities and what the participants think and feel about the training and so forth. This level, therefore, can be measured using attitude rating instruments such as questionnaires, observations, and interviews (verbal feedback) during and after the training. Measuring reactions objectively is very important because favourable reactions to training do not necessarily, by themselves, guarantee that learning has occurred (Kirkpatrick & Kirkpatrick, 2005). However, the participants' reactions have important implications for Level 2 (learning), for example, negative reactions almost certainly reduce the possibility of learning. In this study, teachers' reaction related to the training programme in the use of GeoGebra were captured using a post-training questionnaire and semi-structured interviews.

Level 2: Evaluating learning

Learning is concerned with the extent to which the learners acquire or gain the intended knowledge, skills and attitudes, as well as their commitment and confidence based on their involvement in the learning process. In other words, it can be demonstrated by measuring what the learners have and have not learned, what they think they will be able to do differently as a result, how confident they are that they can do it, and how motivated they are to make changes. Kirkpatrick and Kirkpatrick (2010) define learning "as the extent to which learners change attitudes, improve knowledge, and/or increase skill as a result of attending the program" (p. 22). By evaluating the knowledge, skills and attitude before and after the training using tests, interviews or direct observations, a comparison of the results can be done to determine whether learning was successful or not. Kirkpatrick and Kirkpatrick (2009) suggest that measuring learning is very important because no behavioural change (Level 3) can be anticipated unless one attains objectives associated with acquired knowledge, improved skills, or a change in attitudes. However, he goes on to contradict himself by saying that favourable reactions do not guarantee learning. Level 2 (evaluating learning) was measured on learner participants using pre- and post-tests based on the geometry of triangles and quadrilaterals.

Level 3: Evaluating behaviour

Behaviour is defined as the extent to which change in behaviour has occurred and how well learners can implement what they learnt from the training programme. According to Kirkpatrick and Kirkpatrick (2005), this level focuses on discovering whether the training caused the desired behavioural changes in the learners, measured by their ability to apply the new skills acquired in their jobs. Behaviour changes can be assessed by interviewing learners and/or observing them in action when they get back to work/class in order to successfully assess change, the relevance of change, and the sustainability of the change. Learning is assumed to have taken place if learners can exhibit characteristics that visibly show that the learners have changed their behaviours. In the context of the study, this level was assessed to check whether learning conducted by newly trained teachers on GeoGebra usage was transformed into practice, as expounded by Bates (2004), in the classroom by using an observation instrument.

Level 4: Evaluating the results

Results are defined as the extent to which the training impacts the goals of the organisation in terms of profits versus training costs as a result of the learning events and continued reinforcement after training. In other words, this level mainly focuses on achieving organisational goals that are mostly well understood by top management and executives, hence, results are rarely relevant in educational contexts (Embi, Neo & Neo, 2017). Consequently, Kirkpatrick's model is viewed as a diagnostic tool for monitoring learners' progress in order to evaluate whether the training programme offered meets the needs of the trained staff, as well as the organisation offering the staff development programme (Smidt et al., 2009). Since it is very hard to measure the financial gains of organisations and hard to connect these gains to training, testing 'results' was not possible in this study, thus this study focused on reactions, learning, and behavioural changes.

2.9 The limitations of using Kirkpatrick's framework

The use of Kirkpatrick's four-level framework in training evaluation has been highly debated since its introduction 65 years ago. Several discussions on the benefits, challenges and weaknesses of the framework and the four levels have occurred (Alliger & Janak, 1989; Bates, 2004; Holton, 1996; Reio, Rocco, Smith & Chang, 2017; Warren, Allen & Birdi, 1999). Moreover, Kirkpatrick (1994, 2005, 2009, 2010) is not clear about the causal linkages in his framework. On the one hand, he does not rule out the influence of additional factors such as motivation to learn and the environment of the organisation on training outcomes, suggesting that causal linkages between levels are not simple and linear. In one of Kirkpatrick's (1994) more recent publications, he states that "if training is going to be effective, it is important that trainees react favourably" (p. 27), and that "without learning, no change in behaviour will occur" (p. 51). On the other hand, his statements above suggest causal linkages between the levels. For example, trainees' positive reactions lead to an increase in learning, yielding a bigger transfer of learning with sequential favourable outcomes for the organisation (Bates, 2004).

Nevertheless, due to his incoherent statements, Kirkpatrick's framework has been criticised by countless researchers for its assumptions (Alliger & Janak, 1989; Alliger, Tannenbaum, Bennett, Traver & Shortland, 1997; Bates, 2004; Holton, 1996). From the criticism aimed at

Kirkpatrick's framework, one can identify three issues of concern with the framework that may indirectly affect the results of any study. Firstly, the framework assumes that each latter level provides more information than the preceding level (Alliger & Janak, 1989). For instance, a measure in learning is perceived to be more enlightening than a measure in reaction, and so on. This assumption has been challenged by a number of researchers since it may not be applicable to situations where all the levels are measured (Chan & Kong, 2016; Yusoff et al., 2016).

Secondly, the four levels assume to be causally linked, that is, the latter level is caused by the previous level, but research, however, has largely failed to confirm such causal linkages between all the levels. For example, a few studies conducted show weak or no links between reactions and other levels (Alliger et al., 1997). These results are consistent with those of Alliger and Janak (1989), who did a broad study on the four-level framework, but failed to establish statistically significant relationships between the various levels as suggested by Kirkpatrick (1994, 2005, 2009, 2010). Holton (1996) argues that Kirkpatrick's levels are more suited as categorising schemes (a taxonomy of outcomes), hence the framework is not an all-inclusive causal framework. According to Yardley and Dornan (2012), this assumption of causality between levels cannot always be confidently verified scientifically because the framework is somewhat successful at measuring expected results while ignoring unexpected consequences. They further point out that an effort to test causal assumption within a categorisation is fruitless because, by definition, categories classify rather than define abstract ideas derived from specific cases.

Thirdly, the framework assumes that all correlations among levels are positive. However, the results of the few studies conducted on the correlations between and within levels varied widely, further casting doubt on the assumptions of linear causality. For example, even if causal linkages happen to some extent between levels, especially between levels 2, 3 and 4, one cannot confidently draw conclusions that it was the training programme uniquely responsible for these outcomes (Alliger & Janak, 1989; Holton, 1996). In summary, despite its simplicity, numerous strengths, its influence and its ongoing acceptance, it must be acknowledged that Kirkpatrick's framework is not without considerable weaknesses, even though it is widely used in training evaluations, as evidenced by the literature.

2.10 SUMMARY

In this chapter, I provided a brief analysis of GeoGebra as a pedagogical tool and reviewed past studies that directly focus on the impact of GeoGebra on learner performance in geometry. Literature was also provided on teachers' reactions towards in-service training, their acceptance of the use of technology in their classrooms, and critical evaluations of the use of technology in rural school settings. Kirkpatrick's framework as the lens that guided this study was discussed in detail. The literature points to a gap that exists despite other studies that have investigated the influence of GeoGebra in mathematics education. No studies could be found that investigated the difference in trained teachers' classroom practices through the use of GeoGebra and the resultant difference in learner performance in a South African context. Gökmenoğlu and Clark (2015, p. 446) indicate that "an action research study conducted to document the use of professional development knowledge in classroom settings showed that there was limited evidence of teachers' use of the ideas acquired in in-service training programmes in their classroom settings."

Bansilal (2015) finds that, although researchers have conducted many studies on technology usage in the teaching of mathematics, to date, there is still limited research available about how developing countries have engaged the use of technology effectively in their pedagogy. In fact, numerous studies point to the existence of a gap on how teachers instruct with technology, and how learners gain knowledge or skills through this technology.

The next chapter discusses the research methodology of this study, as informed by this literature review.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 INTRODUCTION

This study focused on investigating how the implementation of GeoGebra by teachers newly trained in its use influenced their classroom practice. The impact of this implementation on learner experience and achievement is also explored.

Hence, the main objective of the study was to obtain answers to the following main research question:

- How does the implementation of GeoGebra by teachers newly trained in its use influence their classroom practice as well as learner experience and achievement in the geometry classroom?

In search of answers to the main question, this study was directed by the following sub-questions:

1. How did the teachers react to their training in the use of GeoGebra?
2. How did the teachers implement their training in the classroom?
3. How did the learners react to the use of GeoGebra in the classroom?
4. What was the impact of the use of GeoGebra on the learning that took place in the classroom?

This chapter involves a description of the philosophical views and assumptions directing this study; an explanation of the research approach and research design used; a discussion of the research methods, research norms, research procedure, analysis of data, ethical considerations; and a chapter summary.

3.2 PHILOSOPHICAL VIEWS AND ASSUMPTIONS

In conducting any research, it is important that the philosophical views and assumptions informing the study are clearly defined by the researchers (Chilisa & Kawulich, 2012). Due to the nature of the main research question, two philosophical positions, namely, constructivism-interpretivism and positivism guided the methodology used in this study. The qualitative phase adopted the constructivist-interpretivists' position, while the quantitative phase followed the positivists' stance. These two philosophical views can be characterised through their ontology, epistemology and methodology.

Ontology is concerned with beliefs about reality, while epistemology is concerned with how we know what we claim to know (Babbie, 2011). Methodology is concerned with the procedure that the researcher will use to acquire knowledge. Hence, the researcher's ontological beliefs dictate their epistemological beliefs, which in turn prescribe the research methodology and methods to use in carrying out research. In another way, the researcher's beliefs about the nature of reality influence the kind of relationship the researcher should have with the research participants. The next section therefore provides a detailed discussion of the characteristics of the two mentioned worldviews adopted in this study.

3.2.1 Constructivism-Interpretivism

In contrast with positivists, constructive-interpretative researchers hold a different view of the world. Interpretative researchers believe that there are many, equally valid, interpretations of what is true about nature and human beings. Using their logic, what is real depends on the meaning a person attaches to what is true because truth does not exist without meaning (Ponterotto, 2005; Saunders, Lewis & Thornhill, 2009). The authors further claim that these interpretations are dependent on the context in which they are made and when they are made, that is, they are context and time bound. According to constructivist-interpretivists, reality is subjective, thus it is influenced by a number of factors such as the social environment; the interaction between the researcher and the participants; and the perceptions, experiences, beliefs and values of the individuals involved (Walliman, 2018).

A researcher who accepts the ontological beliefs aligned with the constructivist-interpretivists' worldview of reality chooses to conduct qualitative research to gain an in-depth understanding of what is going on through close interaction with the participants. Interpretivists claim that knowledge is created and developed by participants because truth evolves and changes and, as a result, is based on the perceptions and experiences of the environment around them. Contrary to positivists, the potential influence of the researcher should be acknowledged, sometimes avoided, or sometimes embraced because the researcher observes and interacts with the participants from within as they both socially construct the truth (Babbie, 2011; Ponterotto, 2005; Walliman, 2018). Since the truth is created by how one sees things, it cannot be generalised to situations other than those found in similar contexts. The emphasis on human interpretations of events leads interpretative research to be associated with qualitative research, where rigour of the study is based on the opinion of the reader. A researcher who uses a qualitative research approach commonly uses data gathering instruments such as open-ended questionnaires, observations, focus groups, and semi-structured interviews.

Since I subscribe to both paradigms, I was led by the constructivist-interpretivists' view of reality and how people create knowledge in qualitative research. I utilised a case study design and qualitative methods to gather data that provided answers to my sub-questions, which were concerned with an evaluation of the effectiveness of training programmes. This approach enabled me to gain a deep understanding of how the teacher participants socially constructed knowledge related to the acquisition of skills, abilities and changes in behaviours during and after their training in GeoGebra usage. Open-ended questionnaires, class observation schedules and semi-structured interview protocols for depth were used to collect data.

I interacted directly with the teachers by engaging in open dialogue with them using interviews throughout the training programme and implementation stage so that knowledge construction was done as a collective. I interpreted what I saw, heard and understood from the position of the teachers who experienced the training. This was done without changing the original views of the participants. However, I remained neutral in order to minimise my influence on the decisions taken by participants. Consequently, my ontological and epistemological views about the truth and how knowledge is gained informed the methodologies and methods that I used, which are discussed in detail in the sub-sections below.

3.2.2 Positivism

A researcher with a positivist view of the world believes that reality is objective and independent of the observer and, as such, it can be identified, measured and predicted using scientific methods (Creswell, 2013; Walliman, 2014). In other words, positivists argue that one reliable truth exists that cannot change or be shaped by the researcher (Babbie, 2011). According to Ponterotto (2005), a researcher inclined towards positivism is concerned with seeking answers to such ontological questions as: "What is the form and nature of reality, and what can be known about that reality?" (p. 130). A positivist researcher mainly focuses on obtaining answers to further questions such as: 1) How do we get knowledge? And, 2) How do we discover new knowledge? As a result, positivists concentrate on the relationship between the researcher and the research participants. They further believe that knowledge is discovered through objective measurement.

Positivists think that in order to obtain what is true, the researcher must stay as far away as possible from the participants. The researcher`s role should be to observe and objectively measure the actions of the participants without interacting with them to ensure that the researcher's personal influence or bias does not disturb the reality of the context being studied (Ponterotto, 2005; Saunders et al., 2009; Walliman, 2018). According to Ponterotto (2005), "the relationship between the research and the participants is objective and dualistic" (p. 130). In the process of observing from a distance, the researcher should be able to uncover this universal, absolute and unchanging truth using standardised instruments, fundamental laws and theories already in existence. Thus, according to positivists' view, knowledge exists out there and is only waiting to be discovered. However, to minimise obtaining distorted results due to the researcher's values and bias, the researcher and the participants should be kept completely separate throughout the research process.

Guided by the positivist philosophical views and assumptions, I conducted an experiment to collect quantifiable data, which I gathered using pre- and post-tests and a questionnaire posed to the learners. During the process of data gathering, I observed and recorded the lessons taught without interfering with the learner participants taking part in the quantitative phase of the study. My ontological and epistemological beliefs shaped my decision to employ a quasi-experimental method to draw conclusions from the empirical data gathered.

3.3 RESEARCH DESIGN

Creswell (2012) defines research design "as a procedure for collecting, analysing and reporting research in quantitative and qualitative research" (p. 627). In other words, it is a systematic process in which the selection of a sample size, the site, the research design used and the methods used to gather and analyse the data are clearly defined to answer the research question(s). In order to capture a more complete picture about the best overall assessment of the training programme, a combination of qualitative and quantitative research designs was used. Each method was used to address a separate set of sub-questions in search of answers to the main research question. Hence, the evaluation of the training programme consisted of a qualitative phase focusing on Kirkpatrick's Levels 1 and 3, and a quantitative phase, which concentrated on Level 3 of Kirkpatrick's framework. Level 4 was not considered relevant to this study. Its exclusion is supported by Ulum (2015), who indicates that this level is mostly not relevant to an educational context because it measures institutional or business performance, which may require more time and money to evaluate. Figure 3.1 shows the logical structure of the fieldwork done in which both quantitative and qualitative data were consciously gathered, analysed and interpreted separately in order to understand in depth the phenomenon under inquiry (Miles & Huberman, 1994).

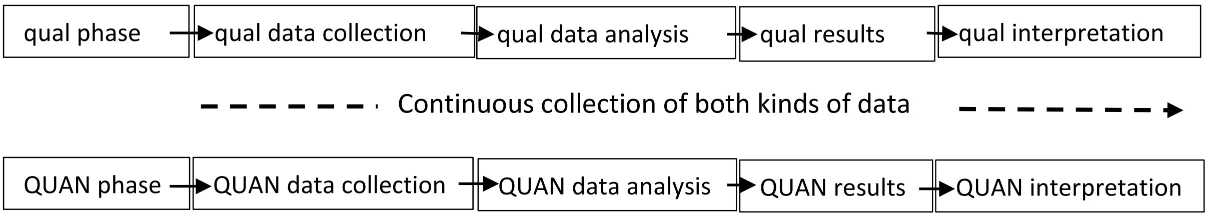

Figure 3.1: Diagram illustrating the qual-QUAN research approaches used in this study

The outline of the research design and methodology used in this study is provided in Table 3.1 below.

Table 3.1 An outline of the research design and methodology

Research approach	This study used a combination of Qualitative and Quantitative approaches without mixing the data (Creswell, 2013).
Philosophical views and assumptions	This study utilised both constructivist-interpretivist and positivist research paradigms (Creswell, 2012; Saunders et al., 2009).
Research design	This study employed a case study design in the qualitative phase (Creswell, 2013; Preskill & Russ-Eft, 2011) and a non-equivalent-control group design with switching replications in two quantitative phases (Trochim, Donnelly, & Arora, 2015).
The aim of this study	This study was aimed at investigating how the implementation of GeoGebra by teachers newly trained in its use influenced learner achievement.
Target site	Ehlanzeni District in Mpumalanga Province, South Africa.
Target population	Grade 10 mathematics teachers and learners.
Participants	Four teachers from four schools and their classes were purposively selected and divided into two groups as follows: Group 1 comprised two schools, two teachers and 89 learners from one circuit. According to the DBE (2016a p. 11), "A circuit is an area of an education district which is demarcated by a MEC for administrative purposes." In a South African context, the MEC is an abbreviation for Member of the Executive Council, which consists of a Premier as the head of the council, and five to ten cabinet members of the provincial government in each province. A circuit, therefore, is a sub-unit of a Provisional Education Department comprising

	between 15 and 30 schools under a specific municipality area or administrative unit headed by a circuit manager within the district. It provides a communication link between schools and the district office. Group 2 involved two schools, two teachers and 76 learners chosen from another circuit. All four schools belonged to the Ehlanzeni district.
Piloting the instruments	A pilot study was conducted prior to the main study. The purpose of the pilot study was to refine the teacher and learner questionnaires before developing the final versions that were used in the main study. The achievement test was validated by the expert who designed the training and teaching activities.
Instruments for data collection	Sub-questions 1 and 2 were answered through teacher questionnaires, lesson observation tool and interviews. Sub-question 3 was answered through a learner questionnaire, achievement tests and questionnaires. Sub-question 4 was answered through learner achievement tests.
Data analysis	Qualitative data from the teacher questionnaires, lesson observations and audiotaped interviews (transcribed verbatim and coded) were analysed using content analysis. Data from the achievement tests and the learner questionnaires were analysed using descriptive statistics and inferential statistics.

3.3.1 Qualitative and quantitative research approaches

Guided by the philosophical views and assumptions discussed in Section 3.1, this study adopted a combination of qual-QUAN research approaches to answer the main research question. In the notation provided above, capital letters denote higher priority, while small letters represent lower priority. This means that in this study, the quantitative method had a dominant status over the qualitative methods (Christensen, Johnson & Turner, 2014). According to Creswell (2013), combining qualitative and quantitative methods "provides a more complete understanding of the research problem than either approach" (p. 32). This implies that the use of one approach can be insuffient to provide an answer to a research question that is diverse in nature. Therefore, it was deemed necessary to use a qualitative method in one phase and a quantitative method in another phase of the same study, yielding two data sets that were analysed seperately. On the one hand, the qualitative approach was concerned with the participants' views and their understanding of the phenomenon under investigation based on their own experiences. On the other hand, the quantitative approach was used to focus on gathering numeric data with the intention of testing for any relationships between variables.

In this study, the main focus was on investigating how the implementation of GeoGebra by teachers newly trained in its use influenced the performance of learners. I found it suitable to collect qualitative and quantitative data seperately since the study was made up of two different groups of participants who were investigated for different reasons. The first group comprised teachers, who provided qualitative data, while quantitative data was gathered from another group consisting of learners in order to get answers to the main research question. The selected research approach was informed by the constructivist-interpretivist and the positivist paradigms discussed in detail in Section 3.1. Saunders et al. (2009) define a research paradigm as “a way of examining social phenomena from which particular understandings of these phenomena can be gained and explanations attempted” (p. 149). The constructivist-interpretivist research paradigm utilises an inductive analysis strategy, which focuses on generating themes and patterns from raw data using inductive reasoning. Alternatively, the positivists’ research paradigm uses a deductive analysis strategy, which relies on testing theory (Armat, Assarroudi, Rad, Sharifi & Heydari, 2018).

As a result, the choice of methodology used in this study was influenced by my own personal experiences, philosophical views and my definition of what constitutes truth, knowledge and how it is acquired. Having been a mathematics teacher for the past 20 years, I believe in the existence of a single truth that can be confirmed by valid rules applicable to everyone else in society (Saunders et al., 2009). This means that once the truth is found, then it can be generalised to other situations. A typical example to illustrate the positivist position in a mathematics classroom is when you test your learners after teaching them a concept. The scores obtained by the learners can provide an indication of whether effective learning for conceptual understanding took place or not. I personally hold the belief that effective learning in the above example can be measured and verified by the scores that learners obtain in a particular test.

At the same time, I also believe in the existence of multiple views that can evolve and change depending on one`s experiences or interactions with the environment in which one lives. For instance, I hold the assumption that the way in which learners learn mathematical concepts requires one to investigate and discover knowledge in order to understand these concepts. In the process of acquiring this knowledge, learners should be allowed time to socially interact, share their different views and reconcile their various perceptions in the process of finding out what works for them. In other words, learners come to know what they are supposed to know through giving them an opportunity to understand, explore and interpret various existing possibilities until they find their own solutions. I agree with the belief that the best way to understand any process is to view it in context because individuals are unique. Uniqueness in people implies that they possess different viewpoints about what constitutes reality and how they come to know what they know (Creswell, 2013).

In conclusion, what we believe to be true and how we study the world around us affects the way in which we view reality (Chilisa & Kawulich, 2012; Saunders et al., 2009). Since I am both a constructivist and positivist, I engaged the teacher participants constantly to achieve a deep understanding of the different perceptions and attitudes they held about their training in the use of GeoGebra. I used questionnaires, conducted interviews for depth, and also perfomed class observations in an attempt to discover knowledge about the participants' perceptions, attitudes, and experiences in the context of their training. The learner participants were tested before and after they were taught using GeoGebra because knowing is not only subjective but can also be measured objectively independent of the reseracher (Babbie, 2011; Creswell, 2013; Ponterotto, 2005). Based on the above, I am fully aware that my results were both grounded in a philosophical position, which is mainly interpretivist in nature, and in data that can be measured and written down numerically. Hence, both research approaches were adopted in order to describe and explore the reality and the practice of geometry instruction within the four different classrooms in search of answers to the main research question. An overview of the three levels of Kirkpatrick's framework showing how they were evaluated and the focus of each evaluation method is shown in Table 3.2.

Table 3.2 Summary of the three types of outcomes and methods of measurement used in this study based on ideas from Kirkpatrick and Kirkpatrick (2010)

Evaluation level and criteria	Focus	Methods of measurement
Level 1: *Reaction*	Participants' perceptions of: • Satisfaction with the training; • Value and perceived usefulness of the training; • Motivation.	Expectations • Post-training teacher questionnaires; • Interviews; • Learner questionnaire.
Level 2: *Learning*	Acquisition of: • Knowledge; • Skills; • Attitudes.	Improvements • Pre- and post-tests.
Level 3: *Behaviour*	Improvement of behaviour based on the real life transfer of:	Effectiveness: • Questionnaires;

Evaluation level and criteria	Focus	Methods of measurement
	• Knowledge; • Skills; • Attitudes.	• Interviews; • Lesson observations.

Table 3.3 comprises the data alignment grid showing the data collection tools, data sources and the analysis techniques used to obtain answers to these sub-questions.

Table 3.3: Data alignment grid

Research Question	Data collection Tool	Data source	Data analysis
1. How did the teachers react to their training in the use of GeoGebra?	i Questionnaires. ii Interviews.	All teacher participants.	➢ Coding. ➢ Content analysis. ➢ Data triangulation.
2. How did the teachers implement their training in the classroom?	i Interviews. ii Observations.	All teacher participants.	➢ Coding. ➢ Content analysis. ➢ Triangulation of data.
3. How did the learners react to the use of GeoGebra in the classroom? 4. What is the impact of the use of GeoGebra on the learning that took place in the classroom?	i. Questionnaires. Pre- and post-tests	All leaner participants. All leaner participants.	➢ Descriptive statistics analysis. ➢ Statistical analysis using $\boldsymbol{t-test.}$ ➢ Descriptive statistics analysis.
			➢ Effect size analysis using Cohen $\boldsymbol{d}$`s formula

The two subsequent sections discuss the qualitative phase and the quantitative phase separately, indicating the study design/method, sampling technique, data collection instruments, standards for quality of conclusions (trustworthiness), and data analysis procedure used in each case in this study as informed by the sub-questions.

3.4 QUALITATIVE PHASE

In the qualitative phase of the study, Kirkpatrick's Evaluation Framework (Levels 1 and 3) was used to investigate teachers' reactions to the training, as well as their behavioural changes as they transferred their knowledge, skills and abilities to the classroom. This allowed for an in-depth exploration of the trained teachers' attributes, such as satisfaction, feelings, attitudes towards the training and so forth.

3.4.1 Design/method

In the qualitative phase, a case study design was used in this study. This comprised employing questionnaires with open-ended questions, observations and semi-structured interviews to gather data from the participants. The qualitative data offered a detailed description of particular events. This phase of the study lent itself to the qualitative research approach since part of this research emphasised discovery, understanding, and a description of the phenomenon under inquiry (Babbie, 2011; Patton, 2002). This kind of research also attempts to understand how different elements of an environment interact to create outcomes, which gives an interpretation of what is happening in a given context (Merriam, 2009).

According to Preskill and Russ-Eft (2011), a case study becomes more suitable:

> When evaluations are conducted for the purpose of understanding the program's context, participants' perspectives, the inner dynamics of situations, and questions related to participants' experiences, and where generalization is not a goal … with an emphasis on the collection of qualitative data (p. 106).

This therefore encompasses descriptive data of events, people, situations, and observed behaviours. It is typically comprised of opinions, beliefs, and the attitudes of individuals who have attended a training programme or those impacted by a programme. The questions and methods used to gather qualitative data tend to be open-ended and less structured, making them more difficult to measure in comparison to quantitative data. However, non-numerical data collected is helpful as it can assist in providing contextual information to clarify potential issues by explaining the 'how' and 'why' behind the issues (Preskill & Russ-Eft, 2011).

3.4.2 Sampling

The target population for the qualitative phase was the Grade 10 mathematics teachers of 2018 in the Ehlanzeni district in the Mpumalanga province, located in South Africa. However, it was not practically feasible to study the whole target population (Christensen, Johnson & Turner, 2014). For that reason, I purposively selected a group of four teachers from four different schools who belonged to two different circuits that are far apart in the Ehlanzeni district. Each circuit comprised two teachers, giving a total of four teachers in the sample. According to Matthews and Ross (2010), purposive sampling is a sampling technique "generally associated with small, in-depth studies with research designs that are based on the gathering of qualitative data and focused on the exploration and interpretation of experiences and perceptions" (p. 167). The four teachers who volunteered to participate in the study met the following criteria:

1) They were available for an informal consultation to determine their willingness to take part in the research before approaching their principals.

2) They volunteered to take part in this study.

3) The four public schools selected belonged to quintiles 1, 2 or 3 and were accessible to me (see Section 1.2).

4) These four selected rural public schools fell under the group of public schools that have continuously underperformed over the years (DBE, 2009, 2010, 2011, 2012, 2013, 2014b, 2014a, 2015, 2016).

I discussed the modalities of this study with the teachers before the research started. Thus, the first meeting with the teachers was informal, followed by a consultation with the principal. This method of identifying the target group ensured that withdrawal by the selected participants during the research process was significantly minimised. When the sample was identified and the participants consulted, the cohort was then divided into two groups that were randomly assigned into experimental and control group by tossing a coin. Each group consisted of two teachers from the same circuit. So, teachers from Schools 1 and 2 were put together to form Group 1, while teachers from Schools 3 and 4 formed Group. This formed the experimental and control groups according to circuits that are located far from each other. Two departmental officials then assisted me by sending out a memorandum inviting the Grade 10 teachers, including those in the target group, to attend training.

3.4.3 Data collection instruments

This section deals with the instruments that were used to collect the qualitative data. The study was guided by Kirkpatrick's Framework, which assists in evaluating training programmes (see Section 2.7.2). To inform Kirkpatrick's Levels 1 (reactions) and 3 (behaviour change), this study utilised questionnaires, semi-structured interviews and lesson observations. In this qualitative phase of the study, the evaluation of the training on the use of GeoGebra was meant to reveal how the participants (teachers) reacted to the training and how they changed their behaviour during and after the training.

Elements such as a positive attitude towards the training; personal comprehension of the content; the ability to reinforce knowledge, skills, and abilities; and the chance to pass on the knowledge gained to the classroom provided evidence of success. The effectiveness of the training was to be revealed through Kirkpatrick's levels of training evaluation shown in the various data collection approaches (see Table 3.3). The three data collection techniques mentioned above were discussed as they relate to each level of the Kirkpatrick Model. The interrelatedness of the three evaluation levels in the Kirkpatrick Model used in this study allowed for the relevance of using different instruments on more than one level of evaluation. A discussion on the data collection instruments and the role of each instrument in providing evidence related to Level 1 and 3 of Kirkpatrick's Framework on evaluating training programmes is presented below.

3.4.4 Kirkpatrick's Level 1 (evaluation of reaction): questionnaires

The data collected through questionnaires were used to inform Sub-question 1: *How did the teachers react to their training in the use of GeoGebra?*

Two questionnaires were administered to the respondents, one before the training and the other directly afterwards. Christensen et al. (2014, p. 71) define a questionnaire as "a self-report data collection instrument that is filled out by research participants." The pre-training questionnaire contained a section on the teachers' demographics and a section with three open-ended questions. The biographic section was designed to gather data from the participants regarding their sex, age, educational level attained, years of employment with the Mpumalanga Provincial

Education Department (MPED), years of teaching Grade 10, and area(s) of expertise in teaching. The three open-ended questions required individual respondents to reflect on their prior knowledge and skills, experiences or behaviour in terms of technology integration before attending the GeoGebra training. In other words, the questions were meant to assess the participants' reactions to their pending GeoGebra training.

The post-training questionnaire probed the participants' reaction (Kirkpatrick's Level 1) to the training in terms of the perceived usefulness, potential and relevance of the GeoGebra training.

The three open-ended questions in the questionnaire (Appendix A) were used to capture information on their reactions (perceptions) to the training programme (Kirkpatrick & Kirkpatrick, 2005). Tripathi and Bansal (2017) believe that if participants have a positive reaction towards training, it is more likely that the training will yield positive results when transferred to the workplace. Thus, items in the questionnaire were meant to measure how the respondents evaluated the quality and relevance of the content, their views and feelings about the training programme, possible challenges they may have faced when teaching with GeoGebra, and the perceived usefulness of the training on the use of GeoGebra in the classroom.

3.4.5 Kirkpatrick's Level 1 (evaluation of reaction): semi-structured interviews

Semi-structured interviews were used to supplement the responses to the questionnaires in order to expand on Sub-question 1: *How did the teachers react to their training in the use of GeoGebra?*

According to Patton (2002), semi-structured interviews are useful when conducting a more intensive study of perceptions, attitudes and motivations than a structured or unstructured interview. A semi-structured interview was used to ensure that items relevant to the research questions were asked, and to give the interviewees an opportunity to provide detailed answers in response to each item. I interviewed all four purposively sampled teachers in order to examine the answers they provided in the questionnaires in greater depth.

Cohen *et al*. (2007) state that "Interviews enable participants – be they interviewers or interviewees – to discuss their interpretations of the world in which they live, and to express how they regard situations from their own point of view" (p. 349). An interview is also defined as a one-on-one interactive dialogue between the researcher and the participant (Christensen et al., 2014). The four teachers were asked identical questions based on their reactions (Kirkpatrick's Level 1)

Three sets of interviews were conducted with all four trained teachers: a post-training interview and pre- and post-lesson observation interviews. The next section will briefly describe the interviews that were conducted with the teachers after the GeoGebra training. This will be followed by a section describing both the pre- and post-lesson observation interviews.

3.4.5.1 Post-training interviews

The post-training interview instrument (Appendix B) comprised 10 questions that were formulated to evaluate the participants' reaction to the GeoGebra training (Kirkpatrick's Level 1).

3.4.5.2 Pre- and post-lesson observation interviews

The four trained teachers were interviewed before presenting their lessons to find out how each one of them had prepared for the lesson. After each lesson, they were interviewed again to gather data on their experiences during the lesson, including how the learners participated, and how they viewed and valued this teaching and learning approach. The pre-observation interview comprised seven questions and the post-observation interview consisted of 10 questions. The questions in the pre- and post-observation instruments sought to determine whether the teachers felt that the training prepared them adequately and whether they believed that GeoGebra is useful in the classroom and has the potential to improve learners' performance (Kirkpatrick's Level 1).

All interviews were audio-recorded with the permission of the interviewees and transcribed verbatim. At the end of each interview, the audio recording was played in the presence of the teacher to allow for confirmation of the accuracy of the recording. It should be noted that, in keeping with the University's ethical principles, all recorded tapes and the transcriptions will be handed over to the university authorities at the end of the study for safe keeping and use in the future as a reference.

3.4.6 Kirkpatrick's Level 3 (evaluation of behavioural change): lesson observations

The teachers were observed in the classroom in order to answer sub-question 2: *How did the teachers implement their training in the classroom?*

The lesson observation tool, which was adapted from Niess et al.'s (2009) instrument, comprised 12 items. The instrument consisted of Section A, B and C with four items each covering: a) Designing and developing technology-mediated learning environments with GeoGebra, b) Teaching, learning and the mathematics curriculum, and c) Assessment and evaluation in the classroom. Due to time constraints and the fact that the researcher is also an educator, each teacher was observed once and this happened outside of normal teaching times according to the arrangements made with the teachers. The purpose of observing the lessons was to evaluate, according to Kirkpatrick's Level 3 (behaviour), how the teachers adapted their teaching to the use of GeoGebra in their classrooms.

Furthermore, the researcher as a non-participating observer observed how the learners engaged in different learning activities provided by the trained teacher. The data collected from the class observations were used to decide whether the knowledge, skills and abilities learnt by the teachers during the training were retained and put into action. Kirkpatrick and Kirkpatrick (2005) propose that the four levels have a causal relationship because positive reactions lead to learning, learning leads to desired behaviour changes in the workplace, and so on. They also suggest that if participants are able to learn and keep the information they received in the training, it is more likely that positive results will be achievable. The participants' success or lack of success in transferring their knowledge, skills and abilities to the learners in the classroom are useful evidence when conducting training evaluations at Level 3. Consequently, the responses gathered from the three instruments about the participants' success in completing Levels 1 and 3 identified them as Level 1 and 3 success cases.

3.4.7 Rigour in qualitative research

According to Lincoln and Guba (1985), the four criteria of rigour (trustworthiness in qualitative research) are: credibility, transferability, dependability, and confirmability. The next section describes the four criteria of rigour and how were they were enhanced in this study.

3.4.7.1 Credibility

In order to ensure that the research findings are credible, as proposed by Marshall and Rossman (2016), the researcher engaged the use of multiple sources of data to assist in understanding the phenomenon under investigation. This process of combining the data from multiple data sources is known as data triangulation and is employed to enhance trustworthiness in the analysis of qualitative data (Creswell, 2011). Triangulation allowed me to verify what the participants said during the interviews and further confirm it through observations. The questionnaires, interview protocol and observation instrument used were evaluated by my supervisor and other experts before their implementation. For instance, items in the classroom observation instrument and interview items were critically reviewed and approved by my supervisors before the instrument was used.

All of the data collected through the various sources mentioned above were interpreted with reference to Kirkpatrick's four-level model on learning evaluation (see Section 2.7.2). At all times I acted neutrally without showing any bias when engaging with the participants during the moments when they were completing the questionnaires, when observing their lessons and when I interviewed them. This was done to minimise my personal influence and enhance the degree of objectivity or truthfulness in the findings. Babbie (2011) points out that an interviewer who remains neutral and interviews the respondents in the same way minimises the degree of unfairness. In addition, the raw data, together with my interpretations, were given for peer review to a colleague who was also a doctoral student at the same institution. This colleague advised me to confirm the accuracy of the transcriptions with the participants first and then move on to focus on the main themes when reporting, instead of providing the entire transcript.

Before final reporting was done, all of the responses from the participants were confirmed with them again to ensure that I had not misrepresented them. The participants indicated that the reporting of their views, as well as their interpretation, concurred with their responses, hence they were fairly represented. This member checking process helped to ensure that the results were sound and authentic (Creswell, 2011; Marshall & Rossman, 2016). Above all, the initial legitimacy of the study was achieved by seeking permission from all the relevant parties and concerned before I conducted any fieldwork.

3.4.7.2 Transferability

Marshall and Rossman (1999) indicate that the researcher can enhance transferability (generalisability) by reporting the study "in a manner accessible to other researchers, practitioners, and policymakers," making an "adequate translation of findings so that others will be able to use them" (p. 197). They further identify the triangulation of data sources through designing a study in which multiple informants, multiple cases, multiple researchers or multiple data-collecting sources are present as a strategy that strengthens the usability of a study’s findings in other settings. As suggested by Marshall and Rossman (1999), I was guided by Kirkpatrick’s four-level model on learning evaluation discussing how the data were collected and analysed. I also provided detailed and in-depth descriptions of the questionnaire, interview, and observation details in order to promote thickness and richness of the findings. These thick and rich descriptions could help later researcher(s) to investigate whether another case is similar or different enough to be considered relevant when compared to other cases studied before. As such, to allow users to decide on the degree of generalisability, a complete and precise report of the study is carried out in this study apropos the questionnaire, the interview, and observation records.

3.4.7.3 Dependability

Bitsch (2005) states that “dependability refers to the stability of findings over time” (p. 86). It involves participants evaluating the findings, interpretation and recommendations of the study to make sure that they are all supported by the data that they have provided to the researcher (Cohen, Manion & Morrison, 2005). To increase the dependability of the findings, this study has provided an audit trail that will allow the readers to evaluate the study settings, or the degree to which variation can be tracked or explained (Anney, 2014; Thomson, 2011). Furthermore, dependability has been ensured by recording all the processes and procedures followed in this study. A complete presentation of the study results has also been provided so as to assist the reader in deciding on the trustworthiness of the research.

Since the qualitative phase of the study used a case study approach, triangulation was used to verify the data gathered from the observations and interviews to establish dependability, mostly in terms of whether the findings were comparable. My supervisors and an external statistical consultant critically analysed the data and the coding system. In preparation for the final write up, I compared their results to ensure that where differences existed, their recommendations were adopted. This was done through numerous consultations with them until a consensus was reached on what to finally include. I also engaged two neutral colleagues (one doctoral and one Master’s student) who were doing qualitative research at the same institution to gain their input. They assisted me with identifying some categories that I did not pick up from the raw data. Their inputs were also implemented in the final write up.

3.4.7.4 Confirmability

Anney (2014) states that confirmability "refers to the degree to which the results of an inquiry could be confirmed or corroborated by other researchers" (p. 279). It is furthermore concerned with establishing that the interpretations of the findings are clearly derived from the data and not influenced by the researcher's views or bias. Member checking was also used so as to ensure the accuracy of the findings in this study (Creswell, 2013). The participants were requested to confirm the correctness of the exact words recorded during interviews. All of the participants accepted that the transcripts represented exactly what they said. To further ensure that the data was confirmable, I provided a clear and detailed record of the study methods and procedures, which Miles and Huberman (1994) call an audit trail. An audit trail allows an external person to examine whether the process of and the key decisions made that have informed the study have been followed (Anney, 2014; Chilisa & Kawulich, 2012).

All of the data sources gathered from the fieldwork through the questionnaires, interview transcriptions, achievement tests and class observations will be handed over to the responsible department at the university for safekeeping and use by others. These data sources will enable the reader to comprehend the background bas on which conclusions were drawn in this study. The raw data obtained from the questionnaires, interviews (audio recordings) and observations will be organised in a retrievable format and stored for verification as well.

3.5 QUALITATIVE DATA ANALYSIS PROCEDURE

The qualitative data was collected to answer the following questions: *1) How did the teachers react to their training in the use of GeoGebra?* and *2) How did the teachers implement their training in the classroom?*

In an effort to obtain answers to the two sub-questions, an inductive content analysis was used on the data collected from the teacher questionnaires, interviews, and classroom observations. The data collection and analysis happened concurrently. The data gathered was broken down into smaller pieces and stored in a created computer database. The data was then manually coded to identify common themes, patterns and relationships relating to the teachers' perceptions of their training. I then read through the data several times while moving back and forth between analysing and collecting data. Constantly reviewing the data allowed me to explore for more details and patterns related to each common theme until I could not get any new information from the participants' responses (Creswell, 2013).

I used this strategy to analyse the data, which enabled me to make meaning of the qualitative data gathered through identifying common categories or themes. Therefore, the data were analysed in such a way that I could establish the extent to which the training contributed to learning in Level 2. Level 2 (learning) was analysed using a deductive analysis on the pre- and post-tests, as well as the learner questionnaire to obtain answers to Sub-question 4; this is covered further in Chapter 5. Therefore, the data analysis presented below concerns the data generated from the teachers through the questionnaire, interviews and class observations, and are applicable to Levels 1 and 3 of Kirkpatrick's framework.

3.5.1 Level 1: evaluation of reaction

At Level l of Kirkpatrick's Model, my assessment focused on how the teachers reacted to the training on the use of GeoGebra. This level offered insights into whether the participants were satisfied, and were able to see the relevance of the training (or not).

3.5.1.1 The questionnaire

In an attempt to make sense of the participants' responses, I carefully analysed the content following the data analysing stages proposed by Miles and Huberman (1994). I initially read and re-read their responses in order to identify their reaction indicators through open coding when analysing and categorising. For instance, reaction comments containing words or phrases such as "I think it will be useful," "Lack of projectors or computers," "Learners will pay attention," "It will make them love geometry and enjoy," and, "I will attend more workshops" indicated usefulness and the practical applicability of GeoGebra. The comments were classified into three categories, namely: 1) Perceived usefulness of GeoGebra in the classroom, 2) Perceived practical applicability of GeoGebra in the classroom, and 3) Perceived positive influence on learner performance. The codes and categories are displayed in Table 3.4.

3.5.1.2 The semi-structured interviews

I used content analysis to explore the data from the transcriptions of the interviews. Although, I used the same coding and categorising strategy. Additional comments were identified that point to the teachers' reactions to their training in the use of GeoGebra (see Table 3.4).

Table 3.4 below shows the coding and categorising systems used to analyse Level 1 (reactions) of the respondents in the questionnaires and interviews.

Table 3.4: Codes for analysing reactions from questionnaires and semi-structured interviews.

Level 1	Categories	Comments from the participants	Instrument(s)
Reaction indicators	Satisfaction.	"I am confident…" "I have learnt a lot of skills…" "I am going to motivate other teachers to…". "It's good for teaching…" "I am motivated…" "I had a slight challenge…which I think needs more practice"	- Questionnaires. - Semi-structured interviews.
	Relevance (Perceived usefulness).	"I think it will be useful…" "Learners will pay attention" "It will make them love geometry and enjoy…) "…see the thing happening practically" "I think they will improve…" "I will attend more workshops…"	- Questionnaire. - Semi-structured interviews.
	Application constraints (Lack of resources)	"Lack of projectors or computers" "Faulty electricity"	- Questionnaire. - Semi-structured interviews.

3.5.2 Level 3: evaluation of behavioural changes

I used the content analysis to analyse the data from the classroom observations. This level was meant to identify whether behavioural changes had occurred in the trained teachers as a result of the training programme. I produced codes and categories from a series of actions performed by the participants when they were teaching in the classroom. My main focus was on capturing data on observable behaviour, such as their confidence level as they demonstrated specific concepts using GeoGebra, their commitment, and whether they were able to motivate learners during the lesson delivery. I also looked at their ability to teach their new knowledge, skills and attitudes gained from the training to their learners using GeoGebra competently (see Table 3.5).

Table 3.5: Coding system for analysing the data generated from class observations

Level 3	Categories	Pre-determined Codes	Instrument
Behaviour change indicators	Confidence.	- Ability to remain sure of the content presented. - The way in which the teacher handled questions from the learners. - Ability to handle errors made using the GeoGebra tool.	Class observations.
	Commitment.	- Ability to put what they learnt into effect. - Achievement of the lesson goals.	
	Motivation.	- Adopting new positive attitudes or beliefs. - Learner encouragement throughout the lesson.	
	Competency.	- Ability to demonstrate proficiency with new knowledge and skills in geometry content. - Ability to use GeoGebra tools during illustrations. - The use of relevant knowledge and skills. - The correct use of geometry terms.	

The next section discusses the quantitative phase, which focused on Level 2 (evaluating learning) which was aimed at providing answers to Sub-question 3.

3.6 QUANTITATIVE PHASE

This section of the study presents a discussion of the research design, data gathering methods used, the sampling of the participants, and the rigour in the quantitative research carried out.

3.6.1 Design/method

3.6.1.1 Non-equivalent group design

I chose to use a non-equivalent quasi-experimental design wherein teachers and learners from four schools participated. This design was employed because of my desire to work with newly trained teachers and their current allocated teaching classes. The design enabled me to determine the effect(s) of implementing GeoGebra in the classroom on learner performance. In this type of design, the experimental group is introduced to an intervention and is then observed as it undergoes a string of changes that occur during the intervention period (Trochim et al., 2015). In the context of this study, intervention refers to teaching and learning using GeoGebra as an instructional tool in the classroom. The assumption was that the School's Management Team randomly assigned learners to classes at the beginning of the year. Moreover, the number of learners in each group was not equal because this study used only those who had willingly decided to participate. Since it was not feasible to randomly assign the participants to the experimental and control groups, there existed a possibility that the two groups were not equivalent in ability level. However, to minimise the possibility that the two groups were not at the same level of readiness, I exposed both groups to a pre-test before the interventions (Christensen et al., 2014). The scores from the pre-test provided a baseline for measuring the learner participants' ability levels in the geometry of triangles and quadrilaterals. Campbell and Stanley (1963) assert that if the treatment and the control group are based on proper recruitment and the similarity is confirmed by pre-test scores, then one can regard the non-equivalent control group "as controlling the main effects of history, maturation, testing and instrumentation" (p.48).

All of the classes used in this study followed their school timetables without disruption from the researcher. The only difference was the introduction and use of GeoGebra as an instructional strategy within the experimental groups during lessons conducted in the afternoons. The addition of a non-randomised control group minimised threats to internal validity.

3.6.1.2 Switching replication design and descriptions

A switching replications design (Trochim et al., 2015) with repeated measures was employed within the non-equivalent control group in the quantitative phase. In a switching replication design (see Figure 3.2), two groups are observed or measured three times for comparison. The first group receives the intervention and a comparison group initially does not receive the intervention between the first and the second observation. The other group is given an intervention between the second and the third observation, while the intervention in the first group is removed. The assumption is that when the removal of GeoGebra results in the reduced mean of post-test scores of the control group, then the teachers` training in GeoGebra usage had no influence on their results (see Figure 3.8). In other words, the two groups swop (switch) their roles at a later point in time, meaning that this design allows all of the participants to receive the intervention by the end of the study. In addition, the influence (carry-over effect) of teachers trained in GeoGebra is also minimised by delaying the start of the second phase in which these teachers were now teaching the control group without GeoGebra.

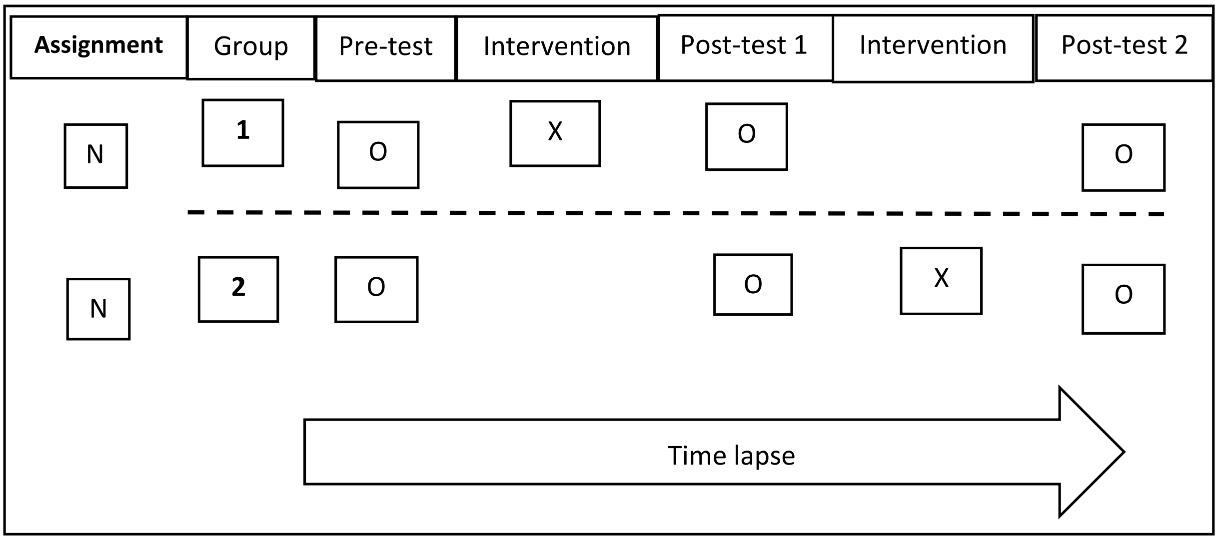

Figure 3.2: Diagram representing the notation of the research design

In Figure 3.2, “N” depicts a non-randomly assigned group, while “O” represents an observation or measurement through the pre- and post-tests. “X” stands for the intervention, and a broken line indicates the separation of non-randomly assigned groups. The arrow shows the time lapse between the cause and the effect when read from left to right (Trochim et al., 2015). Since this design gives the researcher the chance to conduct two independent interventions, it may enhance external validity or generalisability. This design is supported by Trochim and Donnelly (2006), who state that “the switching-replications quasi-experimental design is also strong with respect to internal validity, and because it allows for two independent implementations of the program, it may enhance external validity or generalisability” (p. 231). Allowing both groups to receive the intervention at different times through switching roles was ethically feasible and reduced the chance of the participants from the control group fighting for the intervention.

In this study, contamination due interaction between the groups was minimised by ensuring that Group 1 and 2 were kept separate. The distance maintained by the two groups ensured that the none of the participants in either group were aware of what was happening in the other group. The dropout rate was minimised by ensuring that the intervention period was reasonably short. Being able to identify potential threats to reliability and validity in cause and effect relationships in research is very important, although it is difficult to completely avoid them. Cohen et al. (2007) affirms that in reality, all these forms of threats may not be avoided totally but only minimised in any research process. The use of the switching replication design increased the strength of the overall design adopted in this study.

The use of a technology-mediated instructional method (GeoGebra software) served as the independent variable, while the learners' post-test scores (outcomes) were the dependent variable. The use of this design has been supported by other researchers (Delucchi, 2014; Marti, 2015; White & Sabarwal, 2014), who argue that quasi-experiments provide empirical evidence that can be used to estimate the causal impact of an intervention on the experimental group. A quasi-experiment is one that consists of some of the features of a true experiment, such as an experimental group and control group for comparison, but lacks the random assignment of participants to conditions or an order of conditions. This type of experiment uses pre-existing groups, such as classes at school level, and an independent variable that can be manipulated, unlike in a true experiment (Shadish, Cook & Campbell, 2002; Steiner, Wroblewski & Cook, 2009).

3.6.2 Sampling

The learners of the four Grade 10 teachers who were purposively sampled for training in the use of GeoGebra also participated in the quantitative phase of the study. The sample of study comprised all Grade 10 learners doing mathematics and taught by the newly-trained teachers in the use of GeoGebra. I conveniently assigned learners into experimental and control groups by using their current classes. This approach made it possible for the newly trained teachers to implement GeoGebra instruction using their current teaching classes assigned to them by the SMT at the beginning of the year. In other words, no random assignment of learners to groups was done by the researcher in order to prevent any disruption to classes (Trochim et al., 2015). A total of 165 learners from all four schools participated in the study.

3.6.3 Data collection instruments

Two data collection instruments were used in this quantitative phase, and will mainly be discussed as they relate to each level of the Kirkpatrick Model. The learners' pre- and post-tests and a learner questionnaire were used to obtain answers to Sub-questions 3 and 4. In the quantitative phase, the main focus was on how the learning conducted by the teacher participants that took place within the context of the training influenced learner performance when it was implemented in the classroom. A detailed discussion of each instrument used to gather quantitative data is provided in the next sections.

3.6.4 Kirkpatrick's Level 1 (evaluating reaction): learner questionnaire

Sub-question 3: *How did the learners react to the use of GeoGebra in the classroom?*

After the post-tests, all of the learners from the experimental groups completed a reflection questionnaire. The purpose of this questionnaire was to gather information on how they felt about learning geometric concepts with GeoGebra, equating to Level 1 of Kirkpatrick`s evaluation framework. The learner questionnaire consisted of 19 questions whose responses were to be given on a Likert scale with three options, namely, Yes, Not sure, and No respectively. The learner survey was used to assess their attitude, confidence and commitment towards learning with GeoGebra. More specifically, the items in the questionnaire focused on evaluating how the learners reacted to GeoGebra instruction in the classroom.

3.6.5 Kirkpatrick`s Level 2 (evaluation of learning): pre- and post-tests

Sub-question 4: *What is the impact of the use of GeoGebra on the learning that took place in the classroom?*

In Level 2 (learning), the newly trained teachers taught their learners the geometry of triangles and quadrilaterals with GeoGebra. The learners then wrote pre- and post-tests in order to establish their immediate retention of the content. The pre- and post-tests, consisting of 40 questions split into two sections, were implemented in an attempt to assess the skills and knowledge levels of the learners before and after they were taught with GeoGebra. One section comprised 20 questions related to the geometry of triangles, while the other section contained 20 questions on the geometry of quadrilaterals.

Learners' pre- and post-tests were used to gather quantitative data. The purpose of the pre- and post-tests was to determine the treatment effects of the intervention in order to verify

Kirkpatrick's Level 2 of learning. Each test was one hour long, and learners were allowed to use calculators. All of the learners managed to finish on time. The test consisted of a mixture of multiple choice questions, **Yes** or **No** questions, and matching questions covering all the cognitive levels, as prescribed by the CAPS document based on those proposed in the Trends in International Mathematics Science Study (TIMSS) paper of 1999. Multiple choice questions were designed with at least four alternatives for each item with randomly distributed correct responses to reduce the chances of getting the correct answer by guessing. However, these levels show similarities between the approach in CAPS and the revised form of Bloom`s Taxonomy for learning, teaching and assessment (Krathwohl, 2002). These tests were written in the same class used for lessons. The sections below present samples of the questions contained in the pre- and post-tests.

Before the intervention (learning with GeoGebra), all learners from both the experimental and control groups wrote a pre-test (Appendix C). The purpose of the pre-test was to check on the ability levels of all learners before receiving the intervention, and to determine whether the two group were comparable. After the intervention, the same pre-test items were used in the post-test in both the experimental and the control groups. However, all of the pre-test questions were randomly rearranged to make the post-test a little different from the pre-test to minimise chances of learners recognising them as items from the pre-test thus increasing objectivity. This process of rearranging the test items reduced what Akintade, Ogbonnaya and Mogari (2015) describe as "cognitive bias" (p. 100). The pre-post tests were marked and the marks were recorded in an Excel spreadsheet.

3.6.6 Rigour of quantitative research

Quality measurement is important for research results to be seen as truthful. Two essential elements that are used to measure and evaluate instruments used in data collection are validity and reliability (Christensen et al., 2014). An instrument such as a questionnaire, or test, is considered reliable if it is able to give the same result over and over again when the instrument is re-administered (Trochim & Donnelly, 2006). The reliability of a measure refers to its consistency. Internal consistency reliability is determined by checking the various components of a questionnaire against each other. A Cronbach's Alpha, denoted by $\alpha,$ is commonly used to determine the internal consistency reliability of an instrument used in gathering quantitative data and, as such, was utilised in the reporting in this study.

In addition, a Cronbach's alpha is expressed as a correlation coefficient, and its value ranges from 0 to +1. Conventionally, a Cronbach's Alpha should be 0.70 or higher to retain an item in a scale (Taber, 2018; Tavakol & Dennick, 2011). The Cronbach's Alpha was calculated for the items in the questionnaire to verify the accuracy of the measurement process. A Cronbach's coefficient alpha denoted by α should be equal to or above .70 to ensure internal reliability adequacy (Howitt, Cramer & Howitt, 2011). Validity is essential in any study because it indicates whether an instrument, such as a questionnaire or test, measures or describes what it is supposed to measure or describe (Christensen et al., 2014; Trochim & Donnelly, 2006). Hence, the procedures followed to ensure the validity and reliability of each of the two instruments (the pre- and post-tests and the learner questionnaire) used to gather quantitative data are presented below:

3.6.6.1 Pre- and post-tests

The instrument that I used to measure the learners' achievement was initially evaluated by my supervisors and four colleagues in the mathematics department. All of their input regarding the appropriateness of the content and language usage were implemented. Since the training of the teachers was conducted by an external facilitator (see Section 3.7.2), who prepared all of the training material for the teachers and activities for the learners, he finally evaluated the achievement test. The final content validity assessment of the instrument by the facilitator was done to ensure that all test items were in line with the requirements of the CAPS curriculum. All of his recommendations assisted me in refining the items in the instrument. Moreover, the expert judgement from the workshop facilitator focused on 1) The relevance of the test items, 2) The clarity of the questions, 3) The simplicity of the items, and 4) The ambiguity of the test items to ensure that the teachers were trained in the correct content. The evaluation form obtained from the facilitator regarding content validity, together with his final ratings, is available.

An internal reliability analysis was then performed using the results of the test - re-test to check the reliability of the 40 test questions in their original form using a Cronbach's Coefficient Alpha. The Cronbach's Alpha test showed an overall score of $\alpha = .83$, showing an adequate internal reliability.

3.6.6.2 Learner questionnaire

The learner questionnaire was initially evaluated by my supervisors and pilot tested with a group of 11 learners before it was used in the main study, the full details of which are provided in Section 3.6.1. All recommendations were implemented accordingly. A reliability analysis was then performed to check the reliability of the 19 questions or items in the questionnaire using a Cronbach's Alpha. The Cronbach's Alpha test showed an overall score of $\alpha = .78$, indicating that the scale had acceptable reliability level (Howitt et al., 2011).

3.6.7 Quantitative data analysis

According to Matthews and Ross (2010) and Merriam (2009), data analysis is a process that allows one to make sense out of the data collected in search of answers to the research questions. Quantitative data were collected to answer the following:

> Sub-question 3: *How did the learners react to the use of GeoGebra in the classroom?*
> Sub-question 4: *What is the impact of the use of GeoGebra on the learning that took place in the classroom?*

Statistical analysis was used to describe the quantitative data while displaying the data using tables and graphs (Field, 2009; Marshall, 2016; Morgan, Leech, Gloeckner & Barrett, 2011). The software program used to analyse the quantitative data was the Statistical Package for Social Sciences (SPSS) version 25 data analysis software. However, before the data were captured and analysed in SPSS, all of the gathered information on the pre- and post-tests and the questionnaire was coded by assigning numbers to the learners` scripts followed by data entry. Possible human errors arising from the incorrect capturing of the dataset were checked thoroughly by referring back to the original test scores constantly to ensure that data free from errors were analysed. This SPSS software enabled me to analyse the data generated from the pre- and post-tests and a learner questionnaire using descriptive and inferential statistics, as discussed in detail in the subsequent sections.

3.6.7.1 Analysis of the descriptive statistics

Descriptive statistics are used to describe or summarise information about variables in the data such as the mean, mode median, quartiles, variances, frequencies and others. These measures help the researcher and would-be reader to understand the basic characteristics or properties of the sample data. Additional descriptive statistics in a graphical format, for example, histograms, bar graphs, pie charts, and box plots, to name a few, may be drawn to allow one to graphically examine or describe the data through several visual formats (Christensen et al., 2014). A preliminary analysis of the gathered data were conducted using descriptive statistics to compare the means of the pre-test scores of the two groups to check for normality of data and equality of variances. The pre-test scores were analysed using visual methods to check whether the sample was a true reflection of the population. Graphical displays were done using box and whisker diagrams, histograms and normal distributive curves to determine if the sample data was representative of the sampled population.

In addition, descriptive statistics were obtained using numeric measures of the sample data to highlight the potential relationships between the variables under inquiry. Information regarding the means, variances, standard deviations, frequencies, and percentages of the two groups were provided to summarise and understand the nature of the data gathered from the pre- and post-tests scores and the learners' reflection questionnaire. For instance, to confirm the results from the graphs about the normality of the pre-tests scores, the researcher calculated the means of the two groups. The computed means of the two groups (one taught with GeoGebra versus one taught without GeoGebra) were used to find out whether the two groups' means were comparable in terms of their cognitive levels. This comparison allowed for the formation of comparison groups. The mean of each group was calculated by adding all the scores of the learners in one group and then dividing by the total number of learners in that particular group.

Furthermore, the differences in variances were also calculated to determine the appropriate tests to use when checking the differences in the means of the two different groups. Variance shows the spread or dispersion of the data around the mean. It is calculated by taking the square of the standard deviation (Bryman & Cramer, 2005; Matthews & Ross, 2010). Frequencies and percentages were also used to analyse the data from the learners' questionnaire, which consisted of 19 questions. The items on the reflection instrument focused on learner motivation and how the learners rated the use of GeoGebra as a pedagogical tool. The number of responses on each option were counted and represented as percentages in the frequency tables.

3.6.7.2 Analysis of the inferential statistics

Wolcott, Duarte and Weckerly (2018) define statistical inference as "making a conclusion about the large unknown and unknowable (population) from the known (random sample)" (p. 199). In simpler terms, it refers to making estimates concerning a population using information gathered from a sample drawn using hypothesis testing. Hypothesis testing is a statistical strategy, by mean or standard deviation, used to check an assumption held by the researcher about a measurable characteristic of a population, which may be true or false. This test tells the analyst whether or not his assumption is true. In real life, it is not practical to collect data from the entire target population. The researcher may only consider collecting data from a sample and using the data for analysis and to make conclusions, guesses or inferences about the population from which the sample is drawn using the results generated from the sample (Babbie, 2011; Howitt et al., 2011). Since it was impossible to study the whole population, it was necessary to explore the differences between the means of the two groups in the sample and draw conclusions about the target population.

In addition to an analysis of the descriptive statistics, this study used a variety of tests, including t-tests, Levene's test and the Kolmogorov-Smirnov test. The choice of suitable tests to use depends on whether the data one intends to compare has come from related or unrelated groups (Bryman, 2013; Bryman & Cramer, 2005). Since the data consisted of one independent variable (GeoGebra instruction) and one dependent variable (test scores), t-tests were used to perform a statistical analysis. The use of a t-test was found appropriate because the test scores were numerical and continuous, with equal intervals between two consecutive numbers (Field, 2009). Feng, Huang, and Ma (2017) define a t-test as "as a statistical method to assess whether the difference between the means of two independent samples which follow a normal distribution are statistically significance" (p. 125). Furthermore, statistical significance tells us how likely it is that a result obtained is due to chance (Christensen et al., 2014).

Parametric tests such as t-tests are applicable when the sample data meets certain conditions such as: 1) The data must be normal, 2) The population variances are equal, 3) The data must be interval data, and 4) The scores are independent or unrelated. These conditions are described in detail in the discussion of the results chapter in Section 5.2.1.1 (Bryman & Cramer, 2005; Field, 2014). Hence, the inferential statistics used for the main analysis were independent samples t-tests and paired samples t- tests for predictions. These tests were used to measure whether the mean differences between the scores within and across the two different groups were statistically significant. I performed the t-test because it was necessary to compare the means of the control and experimental groups in order to establish the impact of GeoGebra usage in learning. It was necessary to determine the effects of GeoGebra on the learners' performance using a paired samples t-test within the group and also independent samples t-

tests across the groups to see how similar the two different groups used were. Before conducting the t-test, I established that the control and experimental groups followed a normal distribution by analysing histograms, box-plots of pre-test scores of both groups and performing hypothesis testing using Kolmogorov-Smirnov test. Even though the level of significance provides probability regarding the fact that the observed difference is due to chance, it does not give the size or importance of a difference.

Another test used was Levene's test defined by Vergura, Acciani, Amoruso, Patrono, and Vacca (2009) "as an inferential statistic test used to assess the equality of variance in different samples. It tests that the variances are equal (null-hypothesis) against the alternative hypothesis that at least two variances are different" (p. 4458). Levene's test was used to check if the two unrelated groups were comparable in terms of their ability levels by examining whether their variances in the pre-test scores were equal or not (Creswell, 2013). Performance measures were assessed using pre- and post-tests. The learner participants in the sample wrote these tests, which were based on geometric concepts involving the properties of triangles and quadrilaterals.

A Kolmogorov-Smirnov test was further used to confirm the results on normality obtained using visual methods because the information provided by graphs may be misleading or unreliable and does not guarantee that the data come from a normal distribution in some cases (Ghasemi & Zahediasl, 2012). Common parametric tests such as t-tests can only be employed if certain conditions are met, i.e. a data analysis was conducted using inferential statistics employing t-tests to determine whether there existed statistically significant differences between the means of the group exposed to GeoGebra lessons and the group not exposed to GeoGebra lessons. All of the statistical tests used to determine the probability of obtaining such a difference by chance were done adopting the commonly used 5% as the level of significance, although the percentage may vary (Bryman, 2013; Bryman & Cramer, 2005). In order to determine whether the effects were statistically significant, the effect sizes were calculated using the Cohen d formula to assess the practical significance of the results. Cohen (1998) indicates that any calculated value of d greater than or equal to 0.2 shows a small effect size, d greater than or equal to 0.5 shows a medium effect, and d above or equal to 0.8 indicates a large effect size. Consequently, it is recommended that when reporting results on the significance or lack of significance of an intervention, it is necessary to determine the effect size of the intervention(s) (Field, 2014).

Unlike statistical significance, effect sizes allow one to compare any two test results from two different teaching and learning strategies to see how considerably different they are (Matthews & Ross, 2010). They also help to establish which teaching strategy was more effective. Hattie (2009, p. 8) gives the practical explanation of effect size as:

> To give what the effect sizes mean practically, an effect size of d = 1.0 indicates an increase of one standard deviation. A one standard deviation increase is typically associated with advancing children's achievement by two to three years, improving the rate of learning by 50%, or a correlation between some variable (e.g. amount of homework) and achievement of approximately r = 0.50.

In the same study, he further indicates that "When implementing a new program, an effect size of 1.0 would mean that, on average, students receiving that treatment would exceed 84% of students not receiving that treatment" (p. 8).

3.7 DEMOGRAPHIC INFORMATION OF THE PARTICIPANTS

A detailed summary of the information of the teacher participants is displayed in Table 3.6, while Table 3.7 shows the total number of learner participants according to each schools.

Table 3.6: Summary of the teacher participants in this study

Group	Teacher	Gender	Age	Qualification(s)	Teaching experience (years)
Group 1	Teacher 1	Male	25-39	BSc (mathematics)	2-4
	Teacher 2	Male	50-59	Teacher`s Diploma & ACE (mathematics)	20 or more
Group 2	Teacher 3	Male	25-39	BSc (mathematics & physics)	Less than 2
	Teacher 4	Male	Below 25	BEd (mathematics SP & FET-phase)	Less than 2

In Table 3.6, Teacher 1 refers to the educator from School 1, with Teacher 2, Teacher 3 and Teacher 4 coming from Schools 2, 3 and 4 correspondingly. Information about gender from the table indicates that the participants identified by the purposive sampling strategy were all males. I acknowledge that the six schools I initially visited consisted of five males and one female Grade 10 mathematics teacher. Unfortunately, the female teacher and one of the male teachers did not attend the training, citing transport problems, even though they had signed consent letters and volunteered to participate. The records at the six schools visited indicated that the majority of the female mathematics teachers were teaching Grade 8 and 9. As a result, my final sample remained comprising four males as participants. The researcher intends to recommend that future studies should consider including female participants to investigate if those findings would be different to those achieved in this study.

3.7.1 Additional biographical information of the teacher participants

The following section provides extra biographical information about the teacher participants in addition to the information presented in Table 3.6 The researcher was interested in the information regarding the participants' teaching experience in Grade 10 and any previous knowledge about teaching with educational technology such as GeoGebra.

Teacher 1: Teacher 1 holds a BSc degree in mathematics and teaches the Senior and FET phases. At the time of this study, he had two years of teaching experience and had been at School A for two years, teaching mathematics and Physical Science. The teacher indicated that he only used GeoGebra at University when he did an assignment, but lacked deeper knowledge about its use in the classroom. He pointed out that he had not used any educational technologies in his classroom before.

Teacher 2: This teacher holds a three-year Teacher's Diploma in education and an Advanced Certificate of Education (ACE). He has 14 years of teaching experience and at the time of this study was the Head of Department (HOD) at School B. Besides teaching mathematics, he has also taught Physical Science and Natural Sciences. The teacher had some previous knowledge on how to teach graphs and functions with GeoGebra. However, he confirmed that he had never taught geometry using GeoGebra.

Teacher 3: This teacher holds a degree in Applied Mathematics and physics. He had been in the teaching field for about a year at the time of this study. The teacher indicated that he had no knowledge about GeoGebra at all and had not taught Grade 10 geometry before. He started teaching Grade 10 classes in the year of this study for the first time. He had never used any educational technology in his classroom.

Teacher 4: This teacher is a new graduate who joined the department in April 2018. The teacher had no previous teaching experience at the time of participating in the training workshop. However, he holds a Bachelor of Education degree (BEd.) majoring in mathematics. He can also teach Physical Science.

Table 3.7: Number of learners who took part in the study

Group	School	Number of learners
Group 1	1	48
	2	41
Group 2	3	24
	4	52
Total		$\boldsymbol{n} = 165$

3.7.2 Set-up of the participating schools

The details of each participating school are provided below:

- **School 1** is a quintile 2 school with a total enrolment of 52 learners doing mathematics in Grade 10. However, four learners participated in the research but missed the post-test due to the teachers' strike and were excluded from the final analysis. The infrastructure of this school was good on average. The school has a small computer laboratory, which is not fully operational. The computer-lab has a fitted data projector. The participating teacher brought his personal laptop to use during the lessons conducted in the afternoon after normal lessons. GeoGebra was already installed on the laptop. The only challenge that existed was that of overcrowding since the lab could not cater to 48 learners due to its small size. Despite the challenge of overcrowding, the teacher successfully taught all lessons on the properties of quadrilaterals using GeoGebra. In the first phase of the study, the properties of quadrilaterals were taught using GeoGebra in School 1. In the second phase of the study, the same learners were taught the properties of triangles using a chalk and talk approach.

- **School 2** had 50 Grade 10 mathematics learners and is in quintile 2. However, nine learners participated throughout but missed the post-test due to the teachers' strike and were thus excluded from the final analysis. The infrastructure of this school is very bad. The school classrooms do not have electricity except for one dilapidated classroom with a malfunctioning plug, forcing the teacher to use a long extension cord connected to the administration offices. The teacher brought a personal laptop and data projector to use in the lesson, while I provided all the learners' handouts. The teacher from School 2 taught the properties of quadrilaterals using GeoGebra. In the second phase of the study, the same learners were taught the properties of triangles using a chalk and talk approach.

- **School 3** is a quintile 1 school and had 24 mathematics learners in Grade 10. The school has an acceptable infrastructural set-up, although it has electricity problems in most of the classrooms. The teacher from this school used a personal laptop for lesson delivery in the second phase of the study. I supplied the teacher with a data projector. All 24 learners participated fully in this study. In Phase 1 of the study, the learners from this school were taught the properties of quadrilaterals using a chalk and talk method. In the second phase, the same learners were taught the properties of triangles with GeoGebra.
- **School 4** is a quintile 2 school and had 52 mathematics learners in Grade 10. All of the learners attended the lessons in full. The infrastructure of the school was acceptable, although the majority of the classes did not have electricity. One venue with a working electric plug was identified and used during this study. I provided the teacher from this school with both a laptop and a data projector. This school taught the properties of quadrilaterals using chalk and talk in the first phase. In this second phase of the study, the teacher taught the properties of triangles with GeoGebra.

Overall, 165 learners participated fully in this study. In the first phase of the intervention, 89 learners formed the experimental group (Group 2) and 76 learners formed the control group (Group 1). After Phase 1, the two groups switched roles. In the second phase, Group 1 became the experimental group, while Group 2 became the control group. By the end of the intervention process, both Group 1 and Group 2 had received the treatment albeit on different topics. This means that the teachers who handled both the initial group and the experimental group did not teach the same concepts in which they had received training in the use of GeoGebra (see section 3.8.2).

3.8 Research procedure

The group that taught learners with GeoGebra first in Phase 1 was randomly chosen with the toss of a coin. The results from the toss indicated that two teachers from School 3 and School 4 from circuit X were going to teach without GeoGebra. These two schools formed the control group in the first phase and were labelled as Group 1. The participants from School 1 and

School 2 from circuit Y formed Group 2 and became the experimental group. These group names were maintained throughout the study process to hide the true identities of the schools and participants. The diagram in Figure 3.3 shows a detailed summary of the research procedure after piloting the instruments from start to the end.

3.8.1 Pilot testing of the research instruments

The teacher and learner questionnaires were pre-tested in the pilot study before the main study was conducted in order to test the procedures and the quality of responses. In this case, pilot testing of the two questionnaires was done without necessarily training the teacher and observe him teach because of time and financial constraints. The purpose of the pilot study was thus: 1) To check that all the instructions in the instruments were easy to understand; 2) To improve the design of the research instruments before administering them to respondents in the main study; 3) To test whether the main study was feasible before implementing it; 4) To improve the reliability and validity of the instruments.

One mathematics teacher from a quintile 2 school who had prior experience in using GeoGebra willingly participated in the pilot study. The pilot school had similar characteristics to the schools in the main study. The teacher was provided with the pre- and post-test questionnaires for evaluation in order to help with improving the quality and clarity of the questions that were likely going to cause possible confusion for the participants in the main study, and to eliminate them. An evaluation form was attached to the questionnaires for comments. Furthermore, 25 learner questionnaires were handed out to the learners in his Grade 10 class to go through the questions. The main aim was to give the learners a chance to identify any question(s) that needed rewording or elimination possibly because the learners had difficulties in understanding them or felt that they were irrelevant or duplicated. Only 11 out of 25 questionnaires handed out to the learners were returned with their individual evaluation comments, representing a response rate of 44%.

After the pilot testing of the questionnaires, some questions were removed while others were modified in terms of grammar and language where clarity was needed. For instance, items 8 and 9 in the pre-training instrument were deleted because they were a repetition of item 7; while items 3 and 4 were modified. Item 9 in the post-training instrument was removed, while items 2, 3, 11, 13 and 14 were amended. Only item 3 in the learner questionnaire was deleted because the feedback from the majority of the learners was that they felt that it was not relevant.

All of the respondents were informed of their right to participate voluntarily in the instrument evaluation process. After implementing all of the changes recommended by the teacher and his learners, the actual data collection process followed in the main study.

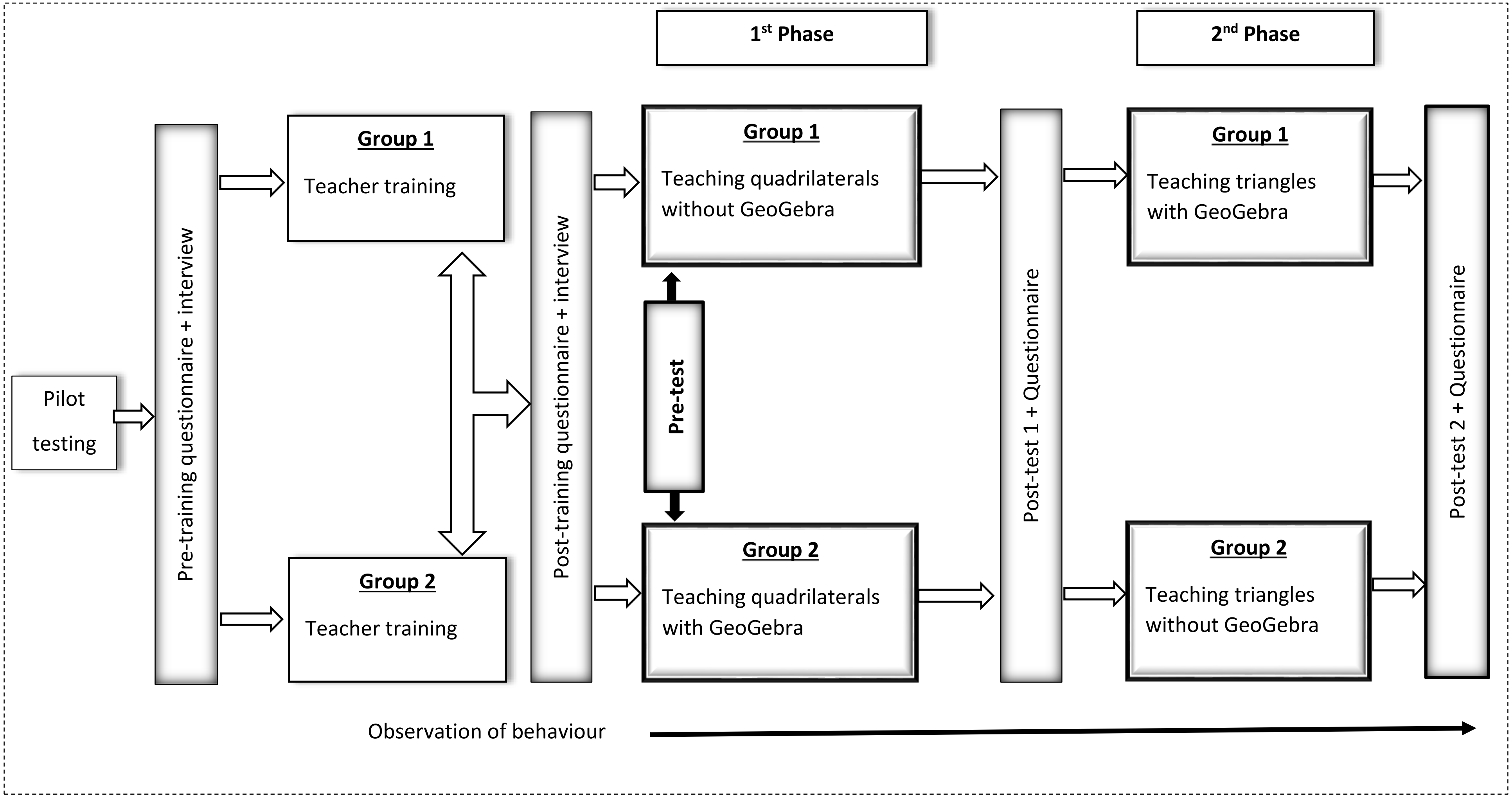

Figure 3.3: The research procedure

3.8.2 The training

Before the training started, I received permission from the school principal to use the school computer laboratory. I hired an external facilitator from one of the local universities who is an expert in GeoGebra and holds a doctorate in mathematics education to train teachers. He is currently working as a senior lecturer in the Department of Mathematics, Science and Technology Education at a local university. The training process of the teachers happened in two days. The teachers in Group 1 attended on day 1 and went away, while the teachers in Group 2 attended their training on day 2. The CAPS-aligned content covered in each training session was prepared by the facilitator and is shown in Table 3.8 and Table 3.9 respectively.

The four targeted teachers were among the trained groups of teachers. Before the training for each day started, I administered the pre-intervention questionnaire to the two participants from each group. The items in the questionnaire accessed their demographic information and previous knowledge on the use of educational technologies. The training schedule started in the afternoon immediately after the normal day`s work and lasted for three hours. In other words, the training ran from 13:00 to 16:00 (see Table 3.8 and 3.9).

Table 3.8: Day 1 Teacher workshop timetable for Group 1

DAY ONE (11April 2018)		
TIME	**ACTIVITY**	**EXTERNAL FACILITATOR**
13:00-14:30	Properties of an *equilateral* triangle.	**Dr B.**
	Properties of an *isosceles* triangle.	
	Properties of a *right-angled* triangle.	
14:30-16:00	Properties of a *scalene* triangle.	
	Interior and exterior angles of triangles.	

Table 3.9: Day 2 Teacher workshop timetable for Group 2

DAY TWO (12 April 2018)		
TIME	**ACTIVITY**	**EXTERNAL FACILITATOR**
13:00-14:30	Properties of a *rectangle.*	**Dr B.**
	Properties of a *square.*	
	Properties of an *rhombus.*	
14:30-16:00	Properties of a *parallelogram.*	
	Properties of a *kite.*	

In both training sessions, the facilitator prepared and provided both the teacher and learner activities and proposed the following new teaching approach involving GeoGebra:

- ✓ Teacher gives learners a sheet of the three different **SHAPES** together with activities;
- ✓ In groups of two, learners work on the activities;
- ✓ In **GEOGEBRA**, the teacher shows learners three different sizes of the **SAME SHAPE;** and
- ✓ Teacher demonstrates properties in GeoGebra discovered by learners at the end of each activity.

The facilitator introduced the teachers in both groups to GeoGebra by exposing them to already designed activities. These activities allowed them to interact with the tools found in GeoGebra's user-interface. The teachers worked on the activities designed and provided by the facilitator using GeoGebra. Throughout the training, the teachers discussed and shared their learning experiences (see Figure 3.4).

Figure 3.4: A picture of teachers during training

3.8.2.1 Training on Day 1

The training session for Group 1 lasted three hours and introduced the teachers to the basic constructions of equilateral, scalene, isosceles, and right-angled triangles, including the exterior angle theorem, using GeoGebra. At the same time, the teachers were taught how to construct the sides, angles and height of each triangle. The facilitator demonstrated how the teachers were going to use GeoGebra to demonstrate the activities in the learners guide he prepared for them when teaching in the classroom (see Figure 3.5). After the training, the teachers in Group 1 were ready to teach their learners the content covered using the teaching approach that the workshop facilitator proposed, while Group 2 teachers taught the same content using the traditional method.

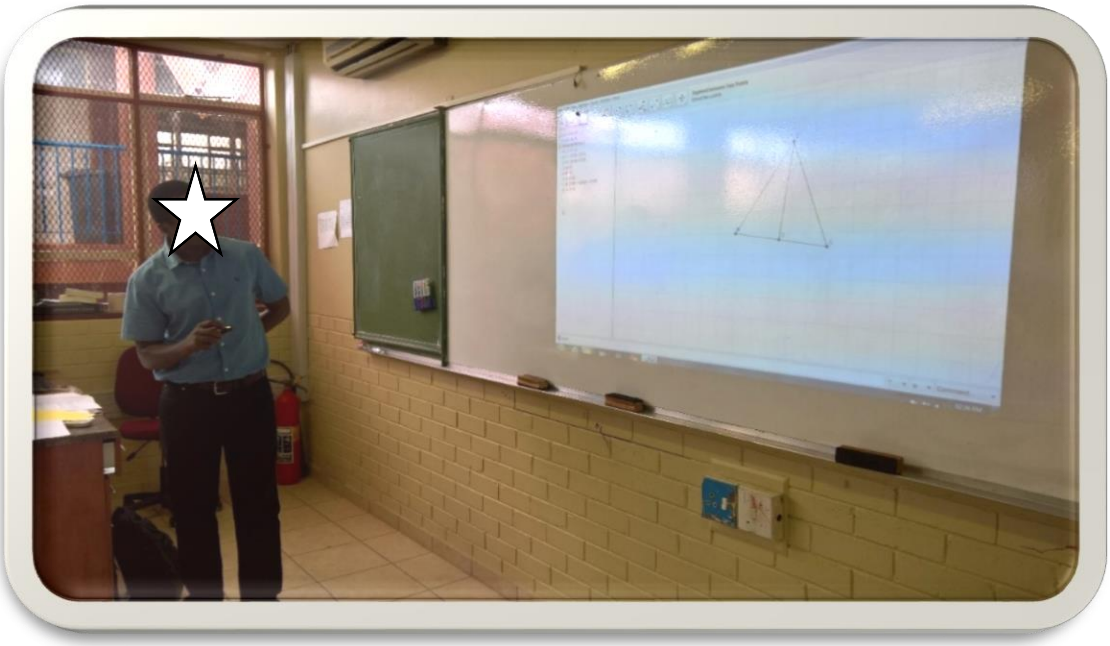

Figure 3.5: The facilitator demonstrating how to use GeoGebra in the classroom

3.8.2.2 Training on Day 2

The two teachers from Group 2 subsequently received a 1-day training on the properties of quadrilaterals on Day 2. The 3-hour training session introduced the teachers to the basic constructions of a square, rectangle, parallelogram, rhombus and kite using GeoGebra. The teachers were also taught how to construct diagonals, interior angles and indicate the dimensions of all five shapes. Finally, the instructor showed the teachers how to teach the properties of quadrilaterals using GeoGebra in preparation for the activities that they were going to use in the classroom. The same facilitator conducted these training sessions for both groups using the same venue, exposing them to similar training conditions and procedures, except for the content covered. This environment ensured that all of the participants operated under the same conditions to minimise possible variations that could arise if training conditions were different. The only thing that differed was the content covered in each training session.

After each training session, the participants were requested to complete a post-intervention questionnaire. This questionnaire accessed information about their perceptions of the training. The participants were also interviewed after the training. The participants in the control group taught the same content on the properties of triangles using the traditional method. After the two workshops, the newly trained teachers were ready to implement the teaching and learning approach proposed by the facilitator using already designed worksheets and pre-constructed dynamic geometry tasks according to the facilitator`s recommendations. These teachers newly trained in the use of GeoGebra were now only expected to adequately go through the GeoGebra tasks and prepare their lessons before they engaged in classroom instruction.

3.8.2.3 Classroom implementation

On each first day of class, I administered the pre-test to all the participating learners. Any learner who missed the test on this first day was not allowed to take it on any other day due to fear of contamination through interactions in other subjects. The same criterion was used for those who missed the post-test. Hence, learners who missed either the pre-test or post-test were not considered in the final analysis. Each learner activity in the learners' guide represented a lesson and needed about 40 minutes teaching time. I observed one lesson at each school. Observing all five lessons was not possible due to work commitments and travelling expenses incurred each time I visited the research site. All of the lessons were conducted in the afternoons and some on Saturdays. This arrangement was agreed upon to avoid disrupting normal classes. The teachers used their normal lessons to teach other topics, as prescribed by the CAPS pacesetter.

All four schools rely on the feeding scheme introduced by the government because the majority of the learners come from poor backgrounds. Through the support of and recommendations from the schools' School Management Teams (SMTs), food was prepared for these learners when attending the scheduled afternoon lessons. With food now provided for the learners after school, they became motivated and attendance improved. Learner handouts for all participating in the experimental groups were provided by me. I only provided copied material with activities to be used by the learners for each lesson. The teachers were already in possession of soft copies of the pre-constructed dynamic geometry tasks that they each received immediately after the training workshop. The diagrams used to demonstrate the properties of each shape on the handout had the same dimensions as the ones designed by the facilitator using GeoGebra. Each shape had three diagrams with different measurements to demonstrate the properties thereof using GeoGebra.

3.9 My role in the research

My role in the research process was twofold. In the qualitative phase of the study, I attempted to access the thoughts and feelings of the teachers through observing and interacting with them, although I tried to remain unbiased throughout (see Section 3.1.1). My position as a neutral observer also permitted me to conduct interviews with the teacher participants (Creswell, 2013). For example, in both training sessions, I observed how the teachers interacted with GeoGebra and what they learnt from the activities provided and administered by the facilitator. I did not participate in the training because I knew how to teach with GeoGebra and was already integrating it in my classes (see section 1.4). At one moment during training, I interviewed one of the target participants who expressed joy and excitement about discovering the potential of GeoGebra. I mainly assisted the facilitator with administrative duties. For instance, I facilitated the distribution of training material and the attendance register to the participants as they entered the training venue. Thereafter, I became an observer until the end of the training. Towards the end of each training session, I administered post-intervention questionnaires to those participants from the target group and thereafter engaged them in post-intervention interviews.

However, my function in the quantitative phase was quite different. For example, during the classroom observations, my presence was theoretically non-existent (see Section 3.1.2). I stayed in the background as much as I could to allow the participants (teachers and leaners) to act independently as if I was not present. I took that position in order to try and minimise bias and subjectivity so that any information I gathered was not contaminated by my personal beliefs. In contrast, I did not observe the control group activities except the writing of pre-and post-tests; the control group followed normal teaching sequence of the same content covered by the experimental group.

3.10 Ethical considerations

Ethically, it is important that a researcher provides a clear outline of the objectives of the study to the participants. With the objective of protecting the personal integrity of all the participants in this study, as well as respecting their moral and cultural values, ethical guidelines were followed during all the stages of this research. Before the study began, I applied and was granted permission by the University of Pretoria's ethics committee, the Head of Department

(HOD) of the Mpumalanga Provisional Department of Education (MPED), the principals, teachers, parents/guardians of the learners, and the learners from the sampled schools. Access to the selected schools was easy for me because all of the participants were willing to be part of this study. There was no prior association between me and the participants despite the fact that I am a teacher from another circuit in the same district. All of the participants signed consent letters, and assent letters in the case of minors (learners) that clearly indicated the role of the participants and my role as the researcher in this study (Botha & Onwu, 2013; Sedibe, 2014).

In this study, the anonymity of the participants became possible through identifying the participating schools, their teachers and learners using number and letters. I informed and assured the participants that their rights and dignity would be respected throughout the study. They were further informed that participation in the research was voluntary. I also assured the participants that no one would identify them by any means as participants in the research or cause statements to be attributed to them. This ethical responsibility was achieved by informing all the participants that they were going to be identified through false names and their faces hidden in pictures in order to hide their true identities.

3.11 CHAPTER SUMMARY

Chapter 3 presented the overall research methodology and procedures used in this study. The research environment was provided, including the way in which the sample was determined. The procedure for selecting and assigning participants to experimental and control groups was clearly described, providing justifications for the choice of the research design and methodology adopted for this study. In doing so, I discussed in detail the issues related to the validity and reliability of the adopted research design, as well as all the instruments used in collecting data. Furthermore, evidence was provided regarding the ethical issues and ways of ensuring that the chosen research design was made stronger through minimising threats to reliability and validity.

The next chapter focuses on the data presentation and analysis.

CHAPTER 4 RESULTS AND DISCUSSION OF THE QUALITATIVE PHASE OF THE STUDY

4.1 INTRODUCTION

In this chapter, the qualitative results and findings obtained from the teachers, who taught the properties of triangles and quadrilaterals using GeoGebra, are reported. The data gathered from the teachers' questionnaires, interviews and lesson observations will be presented and discussed. It is worth mentioning that the qualitative data was used for a completely different purpose as compared to the quantitative data. Alternatively, Chapter 5 will then focus on the quantitative data analysis and the results of the learners` pre- and post-tests and the learner questionnaire.

The results and discussions in Chapters 4 and 5 are aimed at providing answers to the research questions that guided this study. As such, the data presentation and discussions in this chapter will focus on Sub-questions 1 and 2, while the presentation and analysis in Chapter 5 will address Sub-questions 3 and 4. The main research question that directed this study is:

- How does the implementation of GeoGebra by teachers newly trained in its use influence their classroom practice as well as learner experience and achievement in the geometry classroom?

The following sub-questions were addressed in this chapter in search of answers to the main research question:

1. How did the teachers react to their training in the use of GeoGebra?
2. How did the teachers implement their training in the classroom?

In this chapter, the data will be presented in a way that ensures that all important issues relating to Sub-questions 1 and 2 above are addressed guided by the following objectives:

- Looking into how teachers reacted to their training in GeoGebra usage.
- Examining how the teachers implemented their training in the classroom.

In Section 4.2 the results from the questionnaires and interviews are discussed with the aim of providing a description of the newly trained teachers' reactions to their training in the use of

GeoGebra. The findings obtained from the questionnaires and interviews will be used to answer Sub-question 1 and to inform Level 1 of Kirkpatrick's framework. Section 4.3 will present a discussion on how these teachers implemented GeoGebra in their classrooms in order to answer Sub-question 2. This section will also address Level 3 of Kirkpatrick's framework.

4.2 Teachers' reactions to the training on the use of GeoGebra

This section discusses the responses obtained from the four teacher participants regarding their training on GeoGebra usage. The four teachers are referred to as Teacher 1, Teacher 2, Teacher 3 and Teacher 4 for identification purposes. Teacher 1 and Teacher 2 attended the training involving the teaching and learning of quadrilaterals. Teacher 3 and Teacher 4 attended the training about the properties of triangles. Each training workshop was conducted in one day and lasted for 3 hours. Both training workshops focused on how teachers can use GeoGebra in order to help discover the properties of triangles and quadrilaterals through visualisation. The content covered was CAPS-aligned and relevant to Grade 10 learners. Questionnaires and interviews were used to collect the data.

4.2.1 Post-training teacher questionnaire: Kirkpatrick`s Level 1 (reaction)

After the training on GeoGebra usage, all four participants were requested to complete a short questionnaire about their training. Although the responses obtained from the questionnaire may be relevant, they may affect the quality of the findings due to the limited nature of the participants' responses. In other words, a questionnaire can restrict one from obtaining the apparent truth due to a lack of depth because the respondents did not answer the questions in detail. Furthermore, it denied them an opportunity to clarify their responses if the answers they provided were not clearly understood (probing), as compared to interviews, which are discussed in the next section. The questionnaire comprised three open-ended questions that aimed to explore their reaction (Kirkpatrick Level 1) towards the training on the use of GeoGebra. The first question probed the teachers' beliefs/opinions about the usefulness of GeoGebra in their schools and classrooms. The second question examined possible issues that could support or hold back the use of GeoGebra, while the third question was concerned with the teachers' views on how its use could change the learners' performance. Each question will now be presented, along with the teachers' answers, which will be discussed.

Open-ended question 1 *Do you think GeoGebra software will be useful in your own school and classroom environment? Give a brief explanation on your own beliefs/opinions.*

Below are the teachers' full answers to open-ended question 1.

Teacher 1: *Yes, learners will do well when they notice that all the concepts taught are applicable in real-life situations.*

Teacher 2: *I think it will be useful, we only need to fix electricity.*

Teacher 3: *Yes, it makes clear everything about different angles and it can boost learners' confidence about they learn in the classroom.*

Teacher 4: *Yes, it will save me time.*

Based on their responses, it seems that all four participants felt that GeoGebra is useful and relevant as a tool for instructional purposes in the classroom. This suggests a favourable reaction (Level 1) towards GeoGebra's potential as a teaching tool.

Open-ended question 2 *Based on your training experiences, what other factors do you think may aid or hinder the use of GeoGebra?*

Below are the teachers' answers to open-ended question 2.

Teacher 1: *More resources like computers for the learners to use for continuous practice.*

Teacher 2: *Faulty electricity.*

Teacher 4: *Lack of projector or computers.*

Three out of four respondents reported a lack of resources, as well as electrical problems where electricity was available as obstacles that may influence the possible training experience offered by GeoGebra. One respondent (Teacher 3) did not provide a clear response.

Open-ended question 3 *Overall, how do you think your training experiences may influence your learners' achievement/learning?*

Below are the teachers' answers to open-ended question 3.

Teacher 1: *My training will positively influence my learners' achievement now that I am going to share whatever I learnt with them in the classroom.*

Teacher 2: *I am now having materials to investigate properties of polygons. It will help learners to discover the properties without being told.*

Teacher 3: *It will make them love geometry and enjoy to study it during my period.*

Teacher 4: *Learners will pay more attention.*

The responses above indicate that the teachers felt positive about using GeoGebra in the classroom. They believed that it would save time and help maintain learners' attention, thus boosting their confidence and alertness in class. The four respondents anticipated an improvement in learners' achievement and learning as the learners would become motivated when learning through GeoGebra. However, three responses identified potential challenges associated with GeoGebra usage in their schools, although they were willing to use it. Some of the identified setbacks involved a lack of facilities, for instance, computers and data projectors, as well as malfunctioning plugs in the classrooms.

Interpretation of findings: The responses indicated that all of the respondents were confident that GeoGebra is useful in the classroom and can help learners improve their performance. One participant explained that the use of GeoGebra could boost the confidence of learners, while another respondent suggested that it saves on preparation and teaching time. The participants' answers show a favourable reaction (Kirkpatrick Level 1) to the training: the participants displayed positive feelings about the influence of GeoGebra on confidence and learner performance. However, one participant was concerned about the electricity problems in their rural schools, thus it may not be practical to use GeoGebra more often. In those classrooms where electricity was provided, the plugs were malfunctioning. For instance, one respondent reported faulty electricity plugs in the classrooms and indicated that school authorities were not willing to fix these as yet.

Although the majority of the teacher participants lacked prior knowledge and experience of teaching with GeoGebra or other available technologies, they eventually appreciated the usefulness of GeoGebra after the training. They suggested that the use of GeoGebra provides learners with the opportunity to discover the properties of geometric figures without the teacher explaining or telling them all the time. It also saves time and helps maintain learners' attention, thus boosting their confidence and alertness in class. These teachers showed that they were motivated and willing to continue implementing the use of GeoGebra and broaden its use to other topics in mathematics such graphs and functions.

The teachers became more positive and excited over the idea of extending its use to setting examination questions, particularly those on graphs. The four respondents anticipated an improvement in learners' achievement and learning as they explained that learners would become motivated when learning through GeoGebra. However, they also indicated potential challenges associated with GeoGebra usage in their schools, although they were still willing to use it. The identified setbacks involved a lack of facilities, for instance, computers, data projectors, as well as malfunctioning plugs in the classrooms in cases where they were available. Therefore, these teachers were concerned about the practical applicability of GeoGebra in most rural schools due to the non-availability of proper working conditions, facilities and support from principals and departmental officials. In conclusion, the data suggest that the participants were positive, excited, motivated, liked the training, and were willing to use GeoGebra in the classroom, indicating a favourable reaction (Kirkpatrick`s Level 1) to the training. Results are consistent with consulted literature (see section 2.3).

4.2.2 Post-training teacher interviews: Kirkpatrick's Level 1 (reaction)

In addition to the questionnaires, interviews were conducted to further investigate the teachers' reaction to the GeoGebra training.

In the section below, the interviewer's questions will first be presented, followed by a discussion of each teacher's answer respectively. The answers will be supported by verbatim utterances made by the teachers.

> **Interviewer:** *How was your experience throughout the training programme in learning how to teach with GeoGebra?*

Teacher 1:

Initially, the teacher thought that training on how to teach geometry with GeoGebra was a difficult task. However, he went on to say that he enjoyed the whole training session, although he sometimes encountered challenges with the use of construction tools. He stated that he was convinced that GeoGebra is effective for instruction on the properties of geometric shapes and felt confident that he could implement the new teaching strategy competently in his classroom.

The respondent promised to engage in extra practice of the skills he acquired during the training by attending more workshops if they were made available. He told the researcher that he realised the usefulness of GeoGebra when he discovered that it allows the user(s) to change the colours and sizes of geometric shapes without altering the properties of the shape(s) under investigation. He stated:

> *I am confident to use it to the learners ... I have learnt a lot of skills like drawing parallelograms, squares, and yah rhombus ... It`s a good for teaching geometry showing learners properties of squares.*

The teacher also praised the training environment as it provided participants with an opportunity to interact because at one point he struggled with remembering how to use some of the GeoGebra features but quickly got assistance from a colleague.

Teacher 2:

Like the first respondent, Teacher 2 thought it was very difficult and seemingly impossible to learn how to teach with the GeoGebra software when he was first introduced to it. However, he became confident when he realised that learning how to use GeoGebra to teach geometry became easier and easier as he proceeded with the training. He became motivated and promised to recommend it to other teachers. Furthermore, the teacher stated that he would be eager to attend more workshops if they were facilitated in the district. The challenge he faced during training was when he tried to measure the interior angles of polygons alleging that the wrong demonstration of angles could lead to the user and/or learners having misconceptions. The teacher discovered that the dragging feature of GeoGebra is useful when teaching other mathematical concepts such as graphs and functions because of its features that allow for the manipulation of shapes. Below is an extract from his responses:

> *...seemed impossible but after the training it became easier and easier and as the times go on I became confident in using GeoGebra successfully. Actually in measuring the angles sometimes in any figure if there are exterior angles sometimes one can make a mistake in measuring the interior angles and at the time measuring the exterior angle instead of the interior angle, so I think in that one it needs to be demonstrated to learners correctly on how to measure a specific angle.*

Overall, the teacher seemed motivated and confident to use GeoGebra in the classroom.

Teacher 3:

Teacher 3 said that he enjoyed learning how to instruct geometric concepts involving triangles with GeoGebra and did not encounter any problems during the workshop training. He confirmed that he previously had other plans of using GeoGebra to teach. For instance, he explained his initial thought as,

> *My views were to use it for creating problem and never thought of using it during teaching and learning in my classroom.*

All the same, his point of view on the importance of GeoGebra changed after the training as he undertook to use it as a pedagogical tool more often. He further agreed that learning from interacting with other people makes learning easy and fun. Consequently, the teacher believed that his classes would enjoy learning geometry with GeoGebra. Therefore, he was willing to introduce it to his learners as a way of motivating them to realise that a dynamic software like GeoGebra makes the learning of concepts in geometry simple. The teacher described his confidence level as moderate and concluded that his interest in attending further similar workshops may eventually improve his ability to implement GeoGebra effectively as an instructional tool.

Teacher 4:

Teacher 4 confirmed that the he found the workshop interesting throughout the training. He confidently showed that he now could construct any triangle and explore its properties using GeoGebra without a lot of assistance from other teachers. Nevertheless, the teacher confessed that he faced some challenges such as remembering some of the important features needed to do constructions, such as finding the tool for construction. The teacher explained as follows:

> *… I had a slight challenge of remembering how to identify the GeoGebra tools such as where you find the line bisector tool which I think needs more practice.*

The teacher intuitively suggested that there was still a need for him to boost his confidence level in the effective use of GeoGebra in practice. However, he extended his awareness of GeoGebra usage to other geometric figures and indicated that he was prepared to attend related workshops because he believed that its use has an influence on learners’ performance.

Interpretation of the findings: All four respondents stated that they enjoyed the training intervention on GeoGebra usage in the classroom. One respondent indicated that he was fully confident after the training, while the other three respondents were moderately confident in their ability to use GeoGebra when teaching geometry. However, the respondents believed that some of the challenges encountered when using GeoGebra tools during training could be minimised with a lot of practice. Overall, all of the respondents felt motivated and willing to participate in further workshops that promote the use of educational technologies such as GeoGebra. The teachers' satisfaction with the training revealed a positive reaction in terms of Level 1 of Kirkpatrick's framework (see section 2.3).

Interviewer: *What would be your recommendations to other mathematics teachers about GeoGebra?*

Below are examples of the teachers' answers.

Teacher 1: *…Yah, I am going to motivate other teachers to try it in their classes.*

Teacher 2: *…actually I will encourage teachers to use GeoGebra in teaching Euclidean geometry because it makes it more meaningful and clearer than trying to explain to them.*

Teacher 3: *I recommend that other teachers should use GeoGebra when they teaching geometry.*

Teacher 4: *I can tell them to try and use it because It is not only about geometry but it is also useful when you are designing your own test question paper.*

The four respondents showed a positive attitude in terms of recommending GeoGebra to other teachers teaching geometry. On further engagement with the participants regarding how often they thought they would use GeoGebra in their lessons, here is what the respondents said:

Interviewer: How often do you think it is feasible for you to incorporate GeoGebra in your lessons?

Teacher 1: *Well, I think I am gonna use it more often, even other chapters especially the functions.*

Teacher 2: *I can use GeoGebra when reinforcing the content taught, since it is not possible to use it in every class the challenge will be electricity.*

Teacher 3: *…if we using it in our lesson it will be more interesting today they will enjoy the lessons afterwards using GeoGebra. I can apply it in other* *topics for example ... functions. You can show them how to graph a parabola, hyperbola using GeoGebra.*

Teacher 4: *I think l can often use it every day, as long its after school or from extra classes since it can be time consuming setting up projectors and laptops since our period is only 45 minutes so it needs more time.*

All four respondents agreed to use GeoGebra more often and extend it to other topics as well. Their responses gave the impression that they appreciated the relevance of GeoGebra and supported its continued use in the teaching and learning of geometry and other topics in mathematics, which directly links to Level 1.

Interpretation of the findings: Initially, before training, three of the four teachers affirmed that they had little knowledge about GeoGebra and never considered it as tool that could be used for effective teaching and learning. These teachers seemed content with their chalk and talk method of teaching. However, after the training, all the teachers displayed a positive feeling about and attitude towards the use of GeoGebra as an effective pedagogical tool. They perceived it as good and simple mathematical software that can provide visualisation features that are very influential in the cognitive development of learners' geometric concepts and other topics in the mathematics curriculum. All four respondents agreed that GeoGebra is useful for the teaching and learning of geometry and even other topics in mathematics. The extended use of GeoGebra is due to the fact that it has many other useful features that are relevant to numerous mathematics topics such as function, algebra, statistics and many others. In support of their assertions, they went on to indicate that they were more than willing to motivate other teachers to engage in the use of GeoGebra as a teaching tool instead of the traditional chalk and talk method. In addition, one respondent suggested yet another benefit of GeoGebra in that teachers can also use it to design assessment tasks in various mathematics topics.

4.3 TEACHERS' IMPLEMENTATION OF THEIR TRAINING IN GEOGEBRA

After the training, each teacher received soft copies on a memory stick comprising both the paper-based activities and the GeoGebra designed activities to use in the classroom. All of the material given to them regarding the learners' activities was designed and prepared by the facilitator according to the prescribed content framework in the CAPS document. Although the participants saved the material on flash drives, they still requested me to supply them with hard copies for the learners. Hence, I provided copies of the relevant learning material as handouts for the learners. This was done as the teacher participants explained that their schools could not afford to make copies for the learners due to limited financial resources. On the one hand, the teachers in Group 1 covered a total of five lessons focusing on the following concepts: 1) The properties of a *square*, 2) The properties of a *rectangle,* 3) The properties of a *rhombus,* 4) The properties of a *parallelogram,* and 5) The properties of a *kite.* On the other hand, Group 2 teachers covered the following: 1) The properties of an *equilateral* triangle, 2) The properties of an *isosceles* triangle, 3) The properties of a *right-angles* triangle, 4) The properties of a *scalene* triangle, and 5) The interior *and exterior* angles of triangles.

4.3.1 Lesson observations: Kirkpatrick's Level 3 (behaviour)

Four teacher participants were visited and observed while teaching a lesson. I managed to observe one lesson for each teacher, giving a total of four observations. All class visits were scheduled in the afternoon because the teachers were busy with other topics during normal class hours. The above arrangement complied with the research policy requirements stipulated in the letter of permission obtained from the Mpumalanga Department of Education (MPDE). The lessons observed were video recorded and any additional information observed from them were captured when I replayed the videos after the lessons to avoid missing any relevant data. Watching the lessons live several times helped me to identify episodes of interest that may have been omitted during the lesson observations due to human error. All of the observed lessons had a similar lesson structure (Appendix D). In each lesson, the learners started by investigating the properties on paper in pairs before the teacher demonstrated the properties of the geometrical shape under inquiry, whether it be a rectangle, square or equilateral triangle, using GeoGebra. In the implementation stage, the teachers integrated GeoGebra as a pedagogical tool in all of the lessons observed, as described below.

Teacher 1's lesson (investigating the properties of a rectangle using GeoGebra)

Teacher 1 was observed teaching the properties of a rectangle to his learners. The teacher gave his learners handouts with three activities to be completed by the learners during the lesson. The three activities involved the properties related to the sides, angles and diagonals of a rectangle. The worksheet contained three drawn rectangles and their diagonals (see Figure 4.1). The learners were given about 20 minutes to measure all of the sides, interior angles and diagonals in each diagram, and complete the tables that were provided in each activity. The aim was to give the learners an opportunity to discuss the activity in pairs and discover the properties of a rectangle and make conjectures about its sides, angles and diagonals using the three static diagrams. The three diagrams in the worksheet were similar to the ones that the teacher used in GeoGebra (see Figure 4.1).

After discussing the answers provided by the learners in activities 1-3, he then went on to demonstrate how GeoGebra could assist the learners to understand these properties. The demonstrations were done to illustrate the same properties of the three rectangles using GeoGebra, with learners engaged in the discussions. Despite being a novice teacher, he used GeoGebra with confidence, showing a change in behaviour (Level 3) by applying the learning acquired during the GeoGebra training. He made his lesson interesting throughout the presentation and the learners were excited when he started changing the size of the rectangle without affecting the properties discovered on the static diagrams (See Figure 4.2). Table 4.1 gives details regarding what happened during the lesson.

Investigating sides, angles and diagonals of a rectangle

❖ **Given three rectangles**

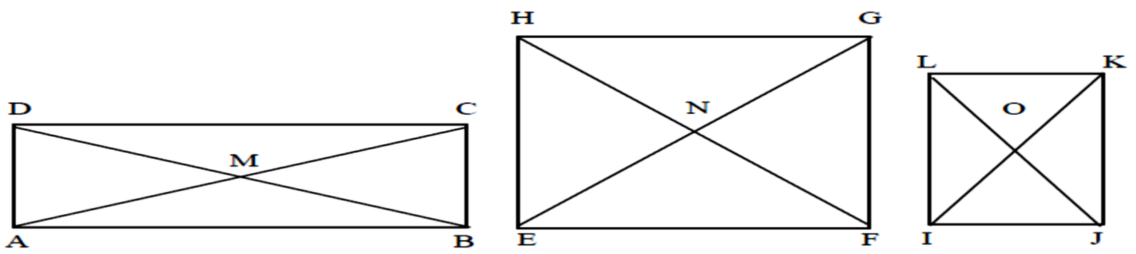

Figure 4.1: Three drawn rectangles and their diagonals in the learners' worksheet

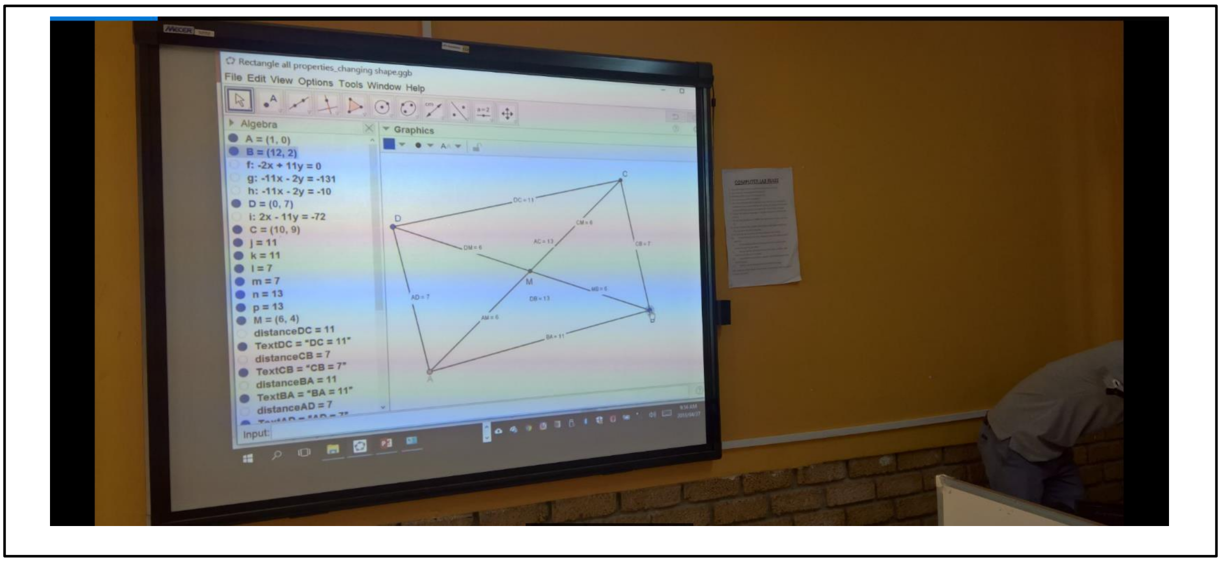

Figure 4.2: Teacher 1 demonstrating all the properties of a rectangle using GeoGebra in a classwork/homework activity to consolidate what was learnt.

Table 4.1: Comparison of Teacher 1's lesson with the requirements in the CAPS document

A. Designing and developing technology- mediated learning environments with GeoGebra

Teachers design and develop authentic learning environments, incorporating appropriate GeoGebra tools and resources to maximise Euclidean Geometry learning in context.

Teachers…

1.	Identify, locate, and evaluate • Geometrical environments, tasks, and curriculum content to integrate GeoGebra tools to support learners' individual and collaborative learning and creativity in Euclidean geometry.	***Researcher`s comments*** **A 1** Yes, because the material was provided by the facilitator.
2.	Create appropriate learning opportunities that incorporate worthwhile Euclidean geometry tasks based on current CAPS needs to support the diverse needs of all learners in learning Euclidean geometry (considering diverse learning styles, working strategies, and abilities using GeoGebra tools).	**A 2** Yes, because the material was provided by the facilitator.
3.	plan instructional strategies to facilitate equitable access to GeoGebra resources for all learners in learning Euclidean geometry.	**A 3** Yes, because the material was provided by the facilitator.
4.	Fit content, instructional strategies and GeoGebra together strongly within the instructional plan.	**A 4** Yes, because the material was provided by the facilitator.

B. Teaching, learning and the mathematics curriculum

Teachers implement curriculum plans that include methods and strategies for applying appropriate GeoGebra tools to maximise learning and creativity in learners.

Teachers …

1.	Incorporate knowledge of all the learners' understandings, thinking, and learning of Euclidean geometry alongside the use of GeoGebra.	**B 1** Yes, because the teacher asked a variety of questions including the "what if…?" type and learners responded.
2.	Facilitate technology-enhanced mathematical learning that fosters creativity and encourages all learners to develop higher-order thinking skills while promoting discourse among learners, as well as among teacher and learners.	**B 2** Partially yes, because the teacher had challenges in implementing it since it was his first time using it in class.
3.	Use GeoGebra to support learner-centred strategies that address the diverse needs of all learners in learning Euclidean geometry as these strategies help learners to become responsible for and reflect on their own learning.	**B 3** Learners actively participated while at the same time they observed as the teacher manipulated the diagrams.
4.	Advocate, model and teach Euclidean geometry with GeoGebra as a procedural routine instead of using it as a tool to develop cognitive growth in learners.	**B 4** The teacher attempted to use GeoGebra for conceptual growth, which demonstrated changed behaviour (Level 3 indicator).

C. Assessment and evaluation in the classroom

Teachers use GeoGebra to facilitate a variety of effective assessment and evaluation strategies.

Teachers …

1.	Apply appropriate GeoGebra tools to assess the learning of Euclidean Geometry, reflect on the assessment results, and communicate those results using a variety of tools and techniques.	**C 1** Yes, because the teacher did not struggle much with the GeoGebra tools in constructing and measuring the sides of the rectangles and throughout the presentation. He remembered and understood the relevant GeoGebra tools and applied them correctly. The teacher was able to transfer knowledge, skills and attitudes to the learners providing evidence of Level 3.

2.	Effectively assess the learners' cognitive growth in the learning of Euclidean geometry.	**C 2** Yes, by probing learners with "what if…?" type of questions throughout the lesson.
3.	Use GeoGebra-enhanced teaching and learning to evaluate learners' understanding and to adjust instructional strategies.	**C 3** Yes, because the teacher tried to extend his knowledge to other quadrilaterals through constructing a square when asked by learners to quickly demonstrate the same properties for a square. The teacher was able to use GeoGebra.
4.	Align the technology (GeoGebra) expectations for assessment tasks and practices with that of classroom activities and expectations.	**C 4** Yes, because the teacher went on to construct the diagram in the homework activity to verify the calculated values.

Teacher 2's lesson (investigating properties of a square with GeoGebra)

Teacher 2 presented a lesson on how to investigate the properties of a square with particular focus on sides, angles and diagonals, leading to specific conjectures. The teacher handed out activities 1-3 covering the required content, as per the CAPS document, for learners to do in pairs. At the end of each activity, the teacher would introduce learners to GeoGebra-designed activities in order to explore the properties using GeoGebra. This teacher had to make a plan to compensate for the classroom, which had no working plugs. He had to look for a long extension cord in order to have access to the nearest working plug. Broken chairs and desks were kept at the back of class, reducing the available learning space. The classroom also had no ceiling and the floor was cracked and dusty. The desks used by the learners were old and in some cases had either loose tops or broken chairs. Despite operating in that learning environment, this teacher presented an interesting and exciting lesson. This teacher had more than 14 years of teaching experience and confirmed that he had previous experience in teaching graphs and functions with GeoGebra. He gave very clear instructions to the learners and the whole lesson was taught in perfect English (see Table 4.2 for a summary).

At the beginning of the lesson, the teacher gave learners handouts with three activities with all of the instructions, which was to be done in pairs. The diagrams combining all the work covered in the three activities are shown in Figure 4.3. The learners were given about 30 minutes to do the tasks without the help of the teacher. When the learners finished doing the activities, they discussed their answers with the teacher. After discussing activities 1-3 with the learners, the teacher then went on to demonstrate all the properties using GeoGebra. The three activities required the learners to work in pairs to measure: 1) All the sides of the three given static squares and complete the tables provided in their learner guide, 2) All the inside angles of all three diagrams and complete the tables, and 3) All the diagonals and the line segments formed from each vertex to the point of intersection of the diagonals in each given square and the two angles formed by each diagonal at each vertex point. In each case described above, the learners were required to complete the conjecture(s) involving the property under investigation in each activity.

After discussing the answers obtained by the learners as a class, the teacher demonstrated the properties discovered by the learners at the end of each activity in GeoGebra. He first opened the already constructed diagrams with similar measurements in GeoGebra. The teacher then measured each diagram using GeoGebra tools to confirm what the learners figured out in each activity. After measuring, the teacher changed the sizes of the squares using the dragging tool in GeoGebra, changed their backgrounds and even rotated them while asking the learners to observe and record any changes. He kept on encouraging his learners to see the changes that occurred regarding the properties under exploration as he manipulated the shapes. Overall, the teacher managed to successfully transfer the knowledge and skills he gained from the training (Kirkpatrick`s Level 3) and also showed a positive attitude towards use of GeoGebra as a pedagogical tool. He was able to implement GeoGebra exceptionally well throughout the lesson. An example of one of the teacher’s demonstrations is shown in Figure 4.4. After the demonstrations, the learners were asked to discuss and do the classwork/homework activity in pairs.

Investigating sides, angles and diagonal properties of a square

❖ **Given the three squares**

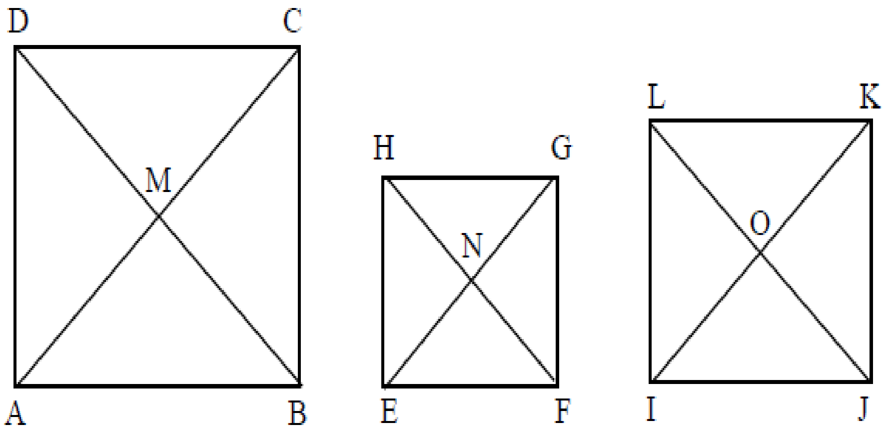

Figure 4.3: Three drawn squares and their diagonals in the learners' worksheet

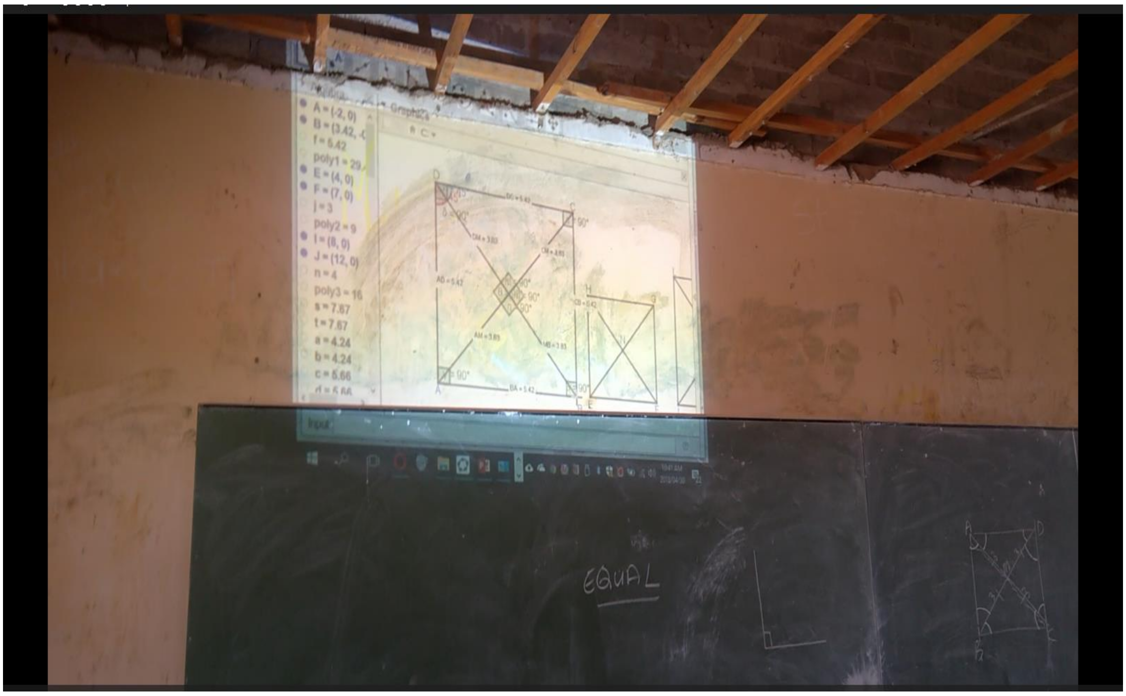

Figure 4.4: Teacher 2's demonstration of the properties of a square using GeoGebra

Table 4.2: Comparison of Teacher 2's Lesson with the requirements in the CAPS document

A. Designing and developing technology-mediated learning environments and with GeoGebra

Teachers design and develop authentic learning environments and incorporate appropriate GeoGebra tools and resources to maximise Euclidean geometry learning in context.

Teachers…

1.	Identify, locate, and evaluate • Geometrical environments, tasks, and content in the curriculum to integrate GeoGebra tools to support learners' individual and collaborative learning and creativity in Euclidean geometry.	***Researcher` comments*** **A 1** Yes, because the material was provided by the facilitator.
2.	Create appropriate learning opportunities that incorporate worthwhile Euclidean geometry tasks, based on current CAPS, which needs to support the diverse needs of all learners in learning Euclidean geometry (considering diverse learning styles, working strategies, and abilities using GeoGebra tools).	**A 2** Yes, because the material was provided by the facilitator.
3.	Plan instructional strategies to facilitate equitable access to GeoGebra resources for all learners in learning Euclidean geometry.	**A 3** Yes, because learner material was provided by the facilitator.
4.	Fit content, instructional strategies and GeoGebra together within the instructional plan.	**A 4** Yes, because the material was designed and provided by the facilitator. He used and taught his learners the correct language of geometry. For example, in his lesson, he used and clearly explained words like bisect, line segments and many others perfectly well to the learners. He was very competent in terms of skills and knowledge of GeoGebra as an effective tool for learning and teaching. In his lesson, he systematically followed a well prepared and sequenced plan in a well-managed classroom, showing strong characteristics of behaviour change (Level 3). The teacher explained and discussed with his learners why and how visualisation

		offered by GeoGebra was relevant to learning. The teacher demonstrated the integration extremely well when he demonstrated the side, angle and diagonal properties of a square while providing clear explanations of what they observed. These indicators confirmed a changed behaviour, which equated to Level 3. As a result, he was able to break down the concepts taught in such a way that made it easy for the learners to gradually understand, thus making them see the connections among the geometric concepts taught.

B. Teaching, learning and the mathematics curriculum

Teachers implement curriculum plans that include methods and strategies for applying appropriate GeoGebra tools to maximise learning and creativity in learners.

Teachers …

1.	Incorporate knowledge of all learners' understandings, thinking, and learning of Euclidean geometry with GeoGebra.	**B 1** Yes, the teacher gave learners a chance to express themselves freely during the lesson.
2.	Facilitate technology-enhanced mathematics that fosters creativity and encourages all learners to develop higher-order thinking skills while promoting discourse among learners as well as among teacher and learners.	**B 2** Yes, this teacher had previous experience in implementing GeoGebra-guided lessons, although not in geometry. The teacher was able to apply his training comfortably (Level 3 indicator). He had used it before when teaching graphs and functions.
3.	Use GeoGebra to support learner-centred strategies that address the diverse needs of all learners in learning Euclidean geometry as these strategies help learners to become responsible for and reflect on their own learning.	**B 3** Yes, learners were given time to observe and discuss as the teacher manipulated the diagrams and asked them questions related to what they observed as he transformed the three diagrams. Learners were also allowed to constantly ask

		questions based on concepts they did not understand.
4.	Advocate, model and teach Euclidean geometry with GeoGebra as a procedural routine instead of using it as a tool to develop cognitive growth in learners.	**B 4** Yes**,** the teacher attempted to use GeoGebra for conceptual growth without any doubts because he posed the *why* and *how* kinds of questions to his learners, forcing them to think. He confidently engaged learners and used simple mathematical language relevant to geometry e.g. words like intersect, bisect, perpendicular (Level 3 indicator). The whole lesson was taught and demonstrated in English. Most of the time, the teacher was reinforcing the concepts learnt and encouraging learners to participate (Level 3 indicator).

C. Assessment and evaluation in the classroom

Teachers use GeoGebra to facilitate a variety of effective assessment and evaluation strategies.

Teachers …

1.	Apply appropriate GeoGebra tools to assess the learning of Euclidean geometry, reflect on the assessment results, and communicate those results using a variety of tools and techniques.	**C 1** Yes, the teacher did this with expertise.
2.	Effectively assess learners' cognitive growth in the learning of Euclidean geometry.	**C 2** Yes, by continually probing learners throughout the lesson for their views and opinions relating to the concepts they learnt.
3.	Use GeoGebra-enhanced teaching and learning to evaluate learners' understanding and to adjust instructional strategies.	**C 3** Yes, because the teacher tried to extend their knowledge to other topics by constructing a parabola when asked by learners to demonstrate where GeoGebra could be used besides in geometry (Level 3 indicator).

4.	Align the technology (GeoGebra) expectations for assessment tasks and practices with that of classroom activities and expectations.	**C 4** Yes, because the teacher also constructed the diagram in the homework activity to indicate the calculated values as they discussed the answers (Level 3 indicator).

Teacher 3's lesson (investigating the properties of an equilateral triangle using GeoGebra)

Teacher 3 was observed teaching about the sides, angles and height of an equilateral triangle. The learners completed the three given activities in pairs. However, Teacher 3, unlike Teacher 2, demonstrated each property at the end of each activity. For instance, Figure 4.6 shows the teacher demonstrating the angle properties of equilateral triangles (Activity 2) using GeoGebra for all three given diagrams. The teacher implemented GeoGebra with success using the knowledge and skills acquired at the workshop, hence the training had a positive influence on the teacher`s performance in the classroom. The attitude of the teacher remained positive and motivated throughout the lesson delivery, which showed that the training changed the teacher's behaviour, providing clear evidence of Level 3 according to Kirkpatrick's framework.

In the demonstration, the teacher rotated each triangle while decreasing and increasing the sizes, enabling learners to see that the size of each interior remained the same in both the algebra and graphic windows despite the orientation of the figures. The teacher did not speak English continuously. For instance, he explained most of the concepts in SiSwati, the learners` home language. However, his demonstrations on the inside angles properties with GeoGebra helped learners to realise that all inside angles are 60° each and add up to 180°. The lesson was interactive. The learners enjoyed the manipulations, and it kept them focused. In the end, most learners were able to discover the conjectures related to interior angles and the sum of these three angles. This suggested that the teacher was able to use GeoGebra, and his successful use thereof informs Level 3, which is concerned with change in behaviour, although his skills in using GeoGebra for teaching were moderate (See Table 4.3). An extract of Activity 2's lesson diagrams is shown in Figure 4.5 below.

Investigating angle properties of an equilateral triangle

❖ **Given the three equilateral triangles**

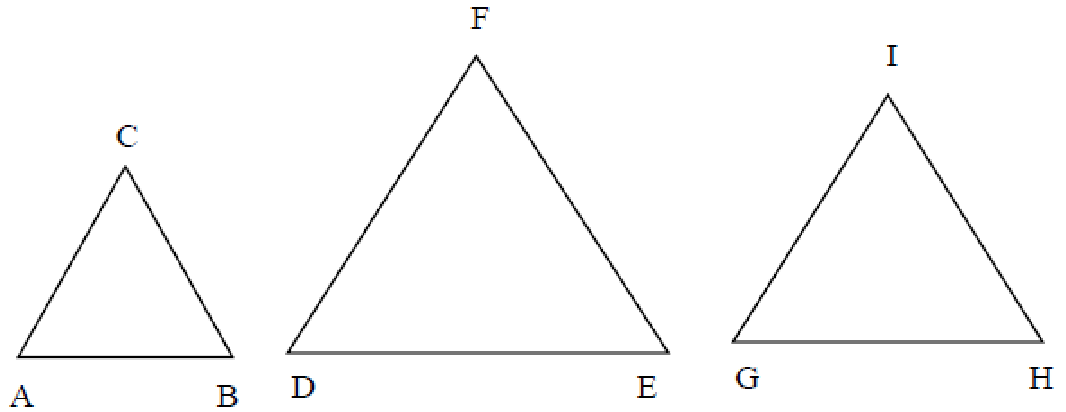

Figure 4.5: Three drawn triangles in the learners' worksheet

Figure 4.6: Teacher 3 demonstrating the angle properties of an equilateral triangle in GeoGebra

Table 4.3: Comparison of Teacher 3's lesson with the requirements in the CAPS document

A. Designing and developing technology-mediated learning environments and with GeoGebra

Teachers design and develop authentic learning environments and incorporate appropriate GeoGebra tools and resources to maximise Euclidean geometry learning in a given context.

Teachers…

1.	Identify, locate, and evaluate • Geometrical environments, tasks, and content in the curriculum to integrate GeoGebra tools to support learners' individual and collaborative learning and creativity in Euclidean geometry.	***Researcher` comments*** **A 1** Yes, because the material was provided by the facilitator.
2.	Create appropriate learning opportunities that incorporate worthwhile Euclidean geometry tasks based on current CAPS needs to support the diverse needs of all learners in learning Euclidean geometry (considering diverse learning styles, working strategies, and abilities using GeoGebra tools).	**A 2** Yes, because the material was provided by the facilitator.
3.	Plan instructional strategies to facilitate equitable access to GeoGebra resources for all learners in learning Euclidean geometry.	**A 3** Yes, because the material was provided by the facilitator.
4.	Fit content, instructional strategies and GeoGebra together within the instructional plan.	**A 4** Yes, because the material was provided by the facilitator. In the classroom, the teacher sometimes struggled to use GeoGebra when demonstrating the various properties under exploration but remained positive and confident (Level 3 indicator). However, he managed his class very well and allowed his learners to interact at all times and discouraged chorus answers. He did not promote and later alone encourage the correct use of geometry terms and language. He taught in SiSwati (first additional language for his learners) most of the time in the classroom Although the teacher only managed to remember and understand the basic skills learnt from the training and never attempted to explore further than these basic skills, his lesson was successful (Level 3 indicator).

B. Teaching, learning and the mathematics curriculum

Teachers implement curriculum plans that include methods and strategies for applying appropriate GeoGebra tools to maximise learning and creativity in learners.

Teachers …

1.	Incorporate knowledge of all learners' understandings, thinking, and learning of Euclidean geometry with GeoGebra.	**B 1** Yes, but not very competently.
2.	Facilitate technology-enhanced mathematics that fosters creativity and encourages all learners to develop higher-order thinking skills while promoting discourse among learners, as well as among teacher and learners.	**B 2** Partially yes because the teacher had challenges in implementing GeoGebra, for instance, constructing the interior angles of triangles.
3.	Use GeoGebra to support learner-centred strategies that address the diverse needs of all learners in learning Euclidean geometry as these strategies help learners become responsible for and reflect on their own learning.	**B 3** Learners were given time to observe and ask questions as the teacher manipulated the diagrams throughout the lesson.
4.	Advocate, model and teach Euclidean geometry with GeoGebra as a procedural routine instead of using it as a tool to develop cognitive growth in learners.	**B 4** The teacher attempted to use GeoGebra for conceptual growth but had a slight problem in explaining it to the learners. He did not encourage his learners to think critically in order to see the connection between the abstract concepts covered by the activities they did in the worksheets and their visual thinking skills.

C. Assessment and evaluation in the classroom

Teachers use GeoGebra to facilitate a variety of effective assessment and evaluation strategies.

Teachers …

1.	Apply appropriate GeoGebra tools to assess the learning of Euclidean geometry, reflect on the assessment results, and communicate those results using a variety of tools and techniques.	**C 1** Partially yes because the teacher ended up learning GeoGebra instead of teaching with it.
2.	Effectively assess learners' cognitive growth in the learning of Euclidean geometry.	**C 2** Not much was observed because the teacher provided the learners with most of the explanations relating to the changes he performed with GeoGebra.
3.	Use GeoGebra-enhanced teaching and learning to evaluate learners' understanding and to adjust instructional strategies.	**C 3** Slightly observed because the teacher kept experiencing difficulties, especially when it came to measuring the interior angles of the three GeoGebra-designed diagrams. However, he implemented GeoGebra (Level 3 indicator).

4.	align the technology (GeoGebra) expectations for the assessment tasks and practices with that of classroom activities and expectations.	**C 4** Yes, because the teacher constructed the diagram in the homework activity to indicate the calculated values (Level 3 indicator).

Teacher 4's lesson (investigating the properties of an equilateral triangle using GeoGebra)

Teacher 4 was observed teaching about the height of an equilateral triangle using GeoGebra. The diagrams of the three equilateral triangles with their heights (dotted lines) drawn are given in Figure 4.7. The paired learners were initially required to measure: 1) The size of the angle formed by the height of the equilateral triangle and the base, 2) The sizes of the angles at the vertex from where the perpendicular line was dropped, and 3) The line segments formed by the height of the equilateral triangle and the base, and record the information in each case in the tables provided in the handout. When the learners finished, the teacher discussed the answers provided by the learners.

The teacher then opened the same diagrams in GeoGebra in order to introduce the learners to the teaching tool. The teacher's aim was to illustrate all the properties discovered by the learners to help them fill in the incomplete conjectures using GeoGebra. This teacher had only been teaching for one month after joining the Department of Education straight from university. Although the teacher was keen on using GeoGebra, he struggled to demonstrate how GeoGebra could be used effectively in teaching and learning the height properties of equilateral triangles. Despite his challenges, the teacher's ability to remain confident and enthusiastic was an indication of a changed behaviour (Level 3) according to Kirkpatrick's framework. He also kept code switching in most of his explanations relating to key features. For example, he explained the concepts of an angle and side bisector in SiSwati (See Table 4.4). The teacher remained positive and composed despite making some mistakes, especially with the angle measurements - he would measure the outside angle when the intention was to measure the inside, especially when he was demonstrating the height as an angle bisector (see Figure 4.8). However, the fact that the teacher was able to implement GeoGebra in the classroom was enough evidence to equate his actions to Kirkpatrick's Level 3. The lesson extract showing Activity 3 taken from learners' guide is shown below.

Investigating properties of an equilateral triangle

❖ **Given are three equilateral triangles with heights (dotted lines) drawn**

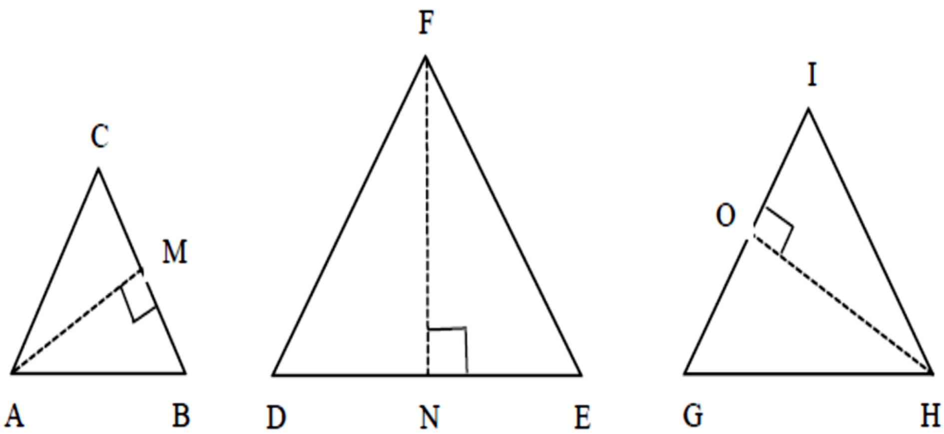

Figure 4.7: Three drawn equilateral triangles and their perpendicular heights in the learners' worksheet

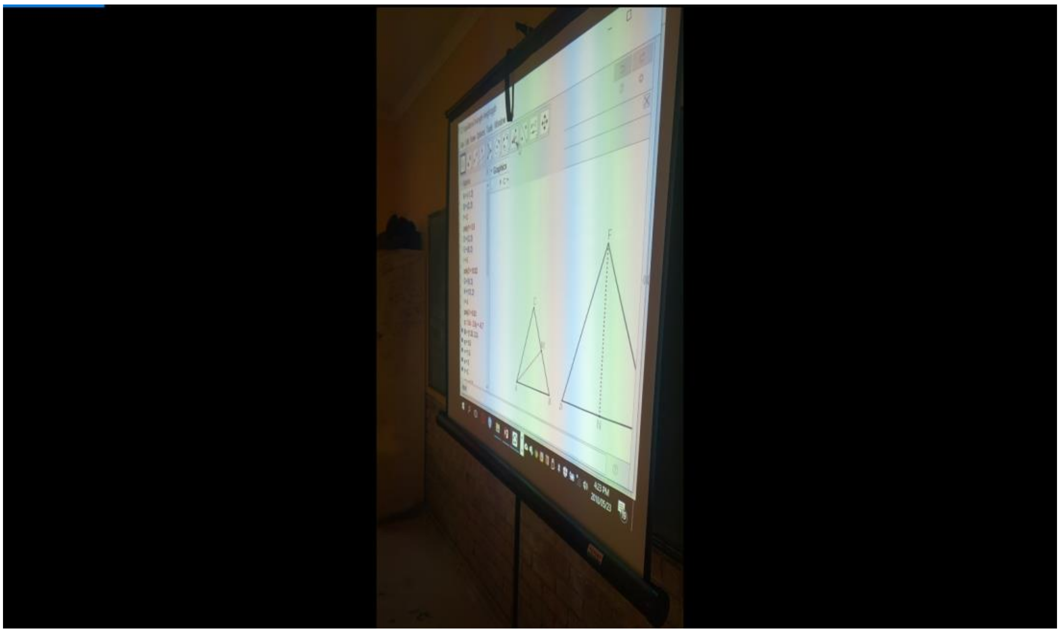

Figure 4.8: Teacher 4 demonstrating the height properties of an equilateral triangle

After the demonstration, the teacher asked the learners to discuss and do a classwork/homework activity which concerned the concepts that were covered in Activities 1 - 3. The lesson is compared with the CAPS document requirements below.

Table 4.4: Comparison of Teacher 4's lesson with the requirements in the CAPS document

A. Designing and developing technology-mediated learning environments and with GeoGebra

Teachers design and develop authentic learning environments and incorporate appropriate GeoGebra tools and resources to maximise Euclidean geometry learning in a given context.

Teachers…

1.	Identify, locate, and evaluate • Geometrical environments, tasks, and content in the curriculum to integrate GeoGebra tools to support learners' individual and collaborative learning and creativity in Euclidean geometry.	***Researcher` comments*** **A 1** Yes, because the material was provided by the facilitator.
2.	Create appropriate learning opportunities that incorporate worthwhile Euclidean geometry tasks based on the current CAPS needs to support the diverse needs of all learners in learning Euclidean geometry (considering diverse learning styles, working strategies, and abilities using GeoGebra tools).	**A 2** Yes, because the material was provided by the facilitator.
3.	Plan instructional strategies to facilitate equitable access to GeoGebra resources for all learners in learning Euclidean geometry.	**A 3** Yes, because the material was provided by the facilitator.
4.	Fit content, instructional strategies and GeoGebra together within the instructional plan.	**A 4** Yes, because the material was provided by the facilitator. However, the teacher struggled with implementing it in the classroom. He also struggled with teaching with GeoGebra when he was demonstrating the property of height in an equilateral triangle. Most of the time he measured the wrong angles. For example, he would measure the outside angle when he wanted to measure the inside angle. He remembered most of the GeoGebra tools but struggled with understanding how to use them appropriately. This visible indicator showing why he struggled suggests a lack of proper planning and preparation before lesson delivery, although he managed to follow the correct sequence of the lesson.

		Classroom management was very good because he discouraged learners from shouting out answers, although some did at times. He was quick to call for order in cases where some learners became disruptive. The teacher praised the use GeoGebra. However, his lesson went on and the learners were engaged throughout (Level 3 indicator).

B. Teaching, learning and the mathematics curriculum

Teachers implement curriculum plans that include methods and strategies for applying appropriate GeoGebra tools to maximise learning and creativity in learners.

Teachers …

1.	Incorporate knowledge of all learners’ understandings, thinking, and learning of Euclidean geometry with GeoGebra.	**B 1** Partially yes because this teacher had less than a month in the teaching field.
2.	Facilitate technology-enhanced mathematics that fosters creativity and encourages all learners to develop higher-order thinking skills while promoting discourse among learners, as well as among teacher and learners.	**B 2** Partially yes, even though the teacher had challenges in implementing GeoGebra in the lesson.
3.	Use GeoGebra to support learner-centred strategies that address the diverse needs of all learners in learning Euclidean geometry as these strategies help learners to become responsible for and reflect on their own learning.	**B 3** Learners were given time to observe as the teacher manipulated the diagrams. However, the teacher applied code-switching in most cases when he tried to explain the concepts. He would switch to SiSwati most of the time.
4.	Advocate, model and teach Euclidean geometry with GeoGebra as a procedural routine instead of using it as a tool to develop cognitive growth in learners.	**B 4** The teacher attempted to use GeoGebra for conceptual growth, although with difficulty. Fortunately, he showed passion (Level 3 indicator) for what he was trying to achieve in that particular lesson.

C. Assessment and evaluation in the classroom

Teachers use GeoGebra to facilitate a variety of effective assessment and evaluation strategies.

Teachers …

1.	Apply appropriate GeoGebra tools to assess the learning of Euclidean geometry, reflect on the assessment results, and communicate those results using a variety of tools and techniques.	**C 1** Yes, but only partially because he mixed up the tools, forcing him to operate on a trial and error approach. For instance, he struggled with marking the distances of the bisected third side.
2.	Effectively assess learners’ cognitive growth in the learning of Euclidean geometry.	**C 2** Yes, by probing learners’ understanding throughout the lesson.

3.	Use GeoGebra-enhanced teaching and learning to evaluate learners' understanding and to adjust instructional strategies.	**C 3** Not observed in the lesson because the teacher remained focused on the height property of equilateral triangles without broadening his demonstration to other geometric figures in his demonstrations.
4.	Align the technology (GeoGebra) expectations for assessment tasks and practices with that of classroom activities and expectations.	**C 4** Not observed because the teacher only discussed the answers to the classwork activity with the learners until the lesson ended.

4.4 CHAPTER SUMMARY

This chapter dealt with teachers' reaction (Level 1) to the training and their behavioural change (Level 3) of Kirkpatrick`s framework following their training and implementation in the classroom. A post-training questionnaire, interviews, and lesson observations were used as instruments for gathering qualitative data during and after the training as teachers engaged in the process of acquiring knowledge, skills, attitudes and the implementation phase.

Level 1 (reaction):

Evidence related to Level 1 (reaction) provided by the teachers from a questionnaire and interviews regarding their training experiences showed that the teachers reacted positively. The interviewed teachers indicated with a high degree of confidence that they enjoyed (Level 1) the training, although the duration was short, and they anticipated being invited to more workshops of a similar nature. They indicated that they were motivated and willing to recommend GeoGebra to other teachers, although the teachers interviewed were concerned with the practical applicability of GeoGebra, especially in rural schools because of a lack of relevant resources.

For instance, all of the interviewed teachers reported faulty electric plugs, perhaps due to vandalism or other factors; a lack of computers let alone laptops and data projectors. Enough evidence was gathered from this fieldwork about the lack of these facilities because three teachers used their personal laptops and the fourth used the researcher`s laptop on request. All of the participants perceived GeoGebra as a relevant and useful tool for instructional purposes in the classroom despite the absence of the relevant resources, showing a positive training experience. Overall, it was clear from their answers that their personal reactions were positive regarding the training and the potential usefulness of the GeoGebra software.

Level 3 (behaviour):

The observed lessons indicated that two out of the four trained teachers ended up learning GeoGebra instead of teaching with GeoGebra alongside their presentations as they tried to overcome some challenges related to the tools used in GeoGebra. However, the learners in the observed classes remained active, focused and participated throughout all the activities they were given. All four teachers continuously reinforced the importance of learning with GeoGebra and encouraged learners to enjoy the benefits of the manipulations offered by the software as compared to static formats. The participants' willingness to encourage other colleagues to use it as well presented acceptable behavioural changes, which equated to Level 3.

Despite the challenges experienced when teaching with GeoGebra, these teachers were still confident (Level 3) that if used effectively in the classroom, GeoGebra could impact positively on learners' achievement. Although the differences in competence levels was evident in their classroom presentations when they taught learners with GeoGebra, the teachers demonstrated positive changes in behaviour, knowledge, skills and attitudes. The overall conclusion drawn from the observations is that all of the teachers were able to use GeoGebra successfully, even though with varying competency. In other words, the four teachers were able to transfer what they learnt during the training to their learners, which provided evidence for Level 3 of Kirkpatrick's framework (See section 2.4).

The next chapter focuses on the presentation and analysis of the quantitative data concerned with Kirkpatrick's Level 1 (reaction) and Level 2 (learning).

CHAPTER 5 RESULTS AND DISCUSSION OF THE QUANTITATIVE PHASE OF THE STUDY

5.1 INTRODUCTION

This chapter presents and discusses the data and findings obtained from the quantitative data analysis. The data used in this chapter were collected in the quantitative phase of this study using a learner questionnaire and pre- and post-tests. The main research question that informed this study is:

- How does the implementation of GeoGebra by teachers newly trained in its use influence their classroom practice as well as learner experience and achievement in the geometry classroom?

The following sub-questions were addressed in this chapter in search of answers to the main research question:

3. How did the teachers react to their training in the use of GeoGebra?
4. What is the impact of the use of GeoGebra on the learning that took place in the classroom?

The data are presented in such a way as to ensure that all relevant aspects pertaining to Sub-questions 3 and 4 stated above are addressed, guided by the following specific objectives of the study:

- Investigating how learners reacted to the use of GeoGebra as a learning tool.
- Assessing how GeoGebra influenced the mastery of geometry concepts and learner achievement in Grade 10 learners in the Mpumalanga province's Ehlanzeni District in South Africa.
- Establishing differences (if any) in terms of learners' achievement in the geometry phases of learners taught using GeoGebra compared to learners taught through the traditional method of talk, pencil and paper.

Therefore, this chapter will address Level 1 (reactions) and 2 (learning) of Kirkpatrick's four-level training evaluation framework to assess the learners' reactions to GeoGebra instruction and how the training programme influenced learner achievement. The quantitative data collected from the participants were analysed to determine the learners` reactions to the

GeoGebra instruction and the influence that GeoGebra had on the learners' performance in triangles and quadrilaterals. This was done using a learner questionnaire, a pre-test, intervention, and post-test protocol.

5.2 QUANTITATIVE DATA ANALYSIS

The data collected from the study were cleaned and organised before the analysis was done. The mean scores for the experimental group and the control group were then statistically analysed to establish whether there had been any statistically significant change in the learners' test scores using hypothesis testing. Hypothesis testing was used as a statistical procedure as it allowed the researcher to use data from the sample to draw conclusions about the population from which the sample was drawn. Christensen et al. (2014, p. 505) define hypothesis testing as "the process of testing a predicted relationship or hypothesis by making observations and then comparing the observed facts with the hypothesis or predicted relationship." A hypothesis is a statement about a relationship(s) between two or more concepts that can be statistically tested for approval or disapproval (Matthews & Ross, 2010). Given the research question outlined in Section 1.5 and the characteristics of the data collected, the appropriate statistical procedure was selected. As such, the following sub-section presents a discussion on the methods that were chosen and used to analyse the statistical data generated from the learner participants.

5.2.1 Learners' reactions to GeoGebra instruction: Kirkpatrick's Level 1

To answer Research Question 3, "*How did the learners react to the use of GeoGebra in the classroom?"*, the learners completed a reflection questionnaire before they wrote the post-test. The purpose of the questionnaire was to obtain their responses on how they evaluated GeoGebra usage in the learning of the properties of quadrilaterals and the properties of triangles. Below are the learners' responses regarding their opinions on their achievement.

5.2.1.1 Learners' reaction to GeoGebra usage in the learning of quadrilaterals

Before the learners were given a post-test to write, they were requested to complete a reflection questionnaire about their reactions to the use of GeoGebra as an instructional tool and how they felt about GeoGebra usage in learning the properties of quadrilaterals. Table 5.1 presents the results.

Table 5.1 Learners` reactions to GeoGebra usage in the learning of quadrilaterals

No	Question	Responses ($\boldsymbol{n = 89}$)				
		Yes (%)	Not sure (%)	No (%)	Did not complete (%)	Total %
1	I am very excited about learning geometry through GeoGebra rather than with pencil and paper.	100	0	0	0	100
2	I learnt and understood a lot about the geometric concepts taught using GeoGebra, more than those taught using paper and pencil.	85	15	0	0	100
3	I prefer all geometry lessons that use GeoGebra, and do not want to use the pencil and paper method from now onwards.	68	25	7	0	100
4	I felt confident doing activities on geometric concepts involving triangles or quadrilaterals after learning these through GeoGebra.	92	7	0	1	100
5	I enjoyed learning geometric concepts taught using GeoGebra rather than with pencil and paper.	97	3	0	0	100
6	GeoGebra`s visual graphics window simplified difficult geometric concepts as compared to the paper and pencil method.	79	11	9	1	100
7	I was able to visualise and answer the questions after each activity.	93	7	0	0	100
8	I was very engaged in the learning process using GeoGebra, more so than when using paper and pencil.	85	14	0	1	100
9	I am now able to make logical assumptions and justifications when attempting to prove riders after the geometry lessons taught using GeoGebra.	37	63	0	0	100
10	I am now able to form better connections between previous knowledge and new knowledge taught using GeoGebra.	92	3	3	2	100
11	I now believe I can do well in Euclidean geometry tasks (including tests), especially concepts taught using GeoGebra.	86	11	1	2	100
12	GeoGebra has helped me to improve my understanding of the geometric concepts explored after the lessons presented.	92	7	0	1	100

No	Question	Responses ($n = 89$)				
		Yes (%)	Not sure (%)	No (%)	Did not complete (%)	Total %
13	GeoGebra has enabled me to make connections between abstract geometric concepts and real-life situations.	82	13	3	2	100
14	The teacher stimulated interest in all lessons taught using GeoGebra, more so than in paper and pencil lessons.	93	1	3	3	100
15	GeoGebra usage has enhanced my understanding of the topics explored after the lessons were presented.	85	9	1	5	100
16	I have overall appreciated the usage of GeoGebra as compared to the paper and pencil method in learning geometrical concepts after the lessons were presented.	75	21	3	1	100
Average %		83	14	2	1	100

Table 5.1 shows that all of the learners (100%) were excited about learning geometry through GeoGebra instruction. Ninety-seven percent of the learners revealed that they enjoyed learning through GeoGebra, and 92% confirmed that they managed to do the activities on the geometry of quadrilaterals with confidence after they were exposed to GeoGebra lessons. Three percent of the learners indicated that they were not sure about whether they enjoyed the lessons or whether they could make a better connection between previous knowledge and the knowledge learned. About 85% of the learners pointed out that they learnt and understood most of the geometric concepts involving the properties of quadrilaterals, demonstrating an increase in knowledge due to the learning intervention. Alternatively, it was established that a few learners (25%) were still unsure about the continued use of GeoGebra in their lessons in the place of the traditional pencil and paper method. In essence, the majority of the learners expressed satisfaction with the teaching and learning method used and the content learned.

Moreover, 83% of the learners, on average, who responded confirmed that GeoGebra had enhanced their understanding regarding the properties of quadrilaterals as compared to the traditional chalk and talk method, while 14% were not sure. This result indicated that the participants reacted favourably to the intervention (GeoGebra instruction) in terms of Kirkpatrick’s Level 1. However, 63% indicated that they were not sure yet about their ability to make valid assumptions and justifications in terms of proofs. This response was not new according to the content covered in this study because the main focus was on laying basic concepts that would assist them when they came to the actual proofs of riders later in the grade, as well as in Grade 11 and 12. On further analysis, the results indicated that the majority of the learners (93%) acknowledged that they were able to do the activities given at the end of each activity after seeing the visual demonstrations done by the teachers. This response suggests that the learners` visual skills may have improved as a result of learning through visualisation.

Most of the learners (92%) agreed that learning through GeoGebra helped them to improve their understanding of geometric concepts, enabling them to see the connections between previous knowledge learnt in previous grades about the properties of quadrilaterals and the new knowledge they acquired during the GeoGebra-enhanced lessons. Although 93% of the learners reported that their teacher stimulated their interest in all of the lessons covered with GeoGebra, about 1% of the learners were not sure. Their decision regarding whether they now preferred learning through GeoGebra or wanted to maintain the paper and pencil method when doing constructions in geometry was still unclear. Overall, the learners’ responses showed that their confidence was boosted and they were excited about learning through GeoGebra in comparison to the traditional chalk and talk method where the teacher is always explaining everything to them without exposing them to dialogues through the lesson. The analysis of the questionnaire responses indicated a positive reaction towards the use of GeoGebra in learning about quadrilaterals.

5.2.1.2 The learners' reactions to GeoGebra usage in the learning of the properties of triangles

The learners completed a reflection questionnaire before a post-test was administered to them. The aim of the questionnaire was to gather information about how the learners reacted to GeoGebra usage in learning about the properties of triangles. Table 5.2 shows their responses.

Table 5.2: Learners' reactions to GeoGebra usage in the learning of triangles

No	Question	Responses ($\boldsymbol{n = 76}$)				
		Yes (%)	Not sure (%)	No (%)	Did not complete	Total %
1	I am very excited about learning geometry through GeoGebra rather than with pencil and paper.	94	3	3	0	100
2	I learnt and understood a lot about the geometric concepts taught using GeoGebra, more than those taught using paper and pencil.	74	23	3	0	100
3	I prefer all geometry lessons that use GeoGebra, and do not want to use the pencil and paper method from now onwards.	61	30	9	0	100
4	I felt confident doing activities on geometric concepts involving triangles or quadrilaterals after learning these through GeoGebra.	77	19	4	0	100
5	I enjoyed learning geometric concepts taught using GeoGebra rather than with pencil and paper.	81	9	8	2	100
6	GeoGebra`s visual graphics window simplified difficult geometric concepts as compared to the paper and pencil method.	58	38	3	1	100
7	I was able to visualise and answer the questions after each activity.	88	9	2	1	100
8	I was very engaged in the learning process using GeoGebra, more so than when using paper and pencil.	83	14	2	1	100
9	I am now able to make logical assumptions and justifications when attempting to prove riders after the geometry lessons taught using GeoGebra.	61	34	5	0	100

10	I am now able to form better connections between previous knowledge and new knowledge taught using GeoGebra.	84	14	2	0	100
11	I now believe I can do well in Euclidean geometry tasks (including tests), especially concepts taught using GeoGebra.	70	30	0	0	100
12	GeoGebra has helped me to improve my understanding of the geometric concepts explored after the lessons presented.	94	6	0	0	100
13	GeoGebra has enabled me to make connections between abstract geometric concepts and real-life situations.	55	39	5	1	100
14	The teacher stimulated interest in all lessons taught using GeoGebra, more so than in paper and pencil lessons.	84	13	2	1	100
15	GeoGebra usage has enhanced my understanding of the topics explored after the lessons were presented.	69	27	3	1	100
16	I have overall appreciated the usage of GeoGebra as compared to the paper and pencil method in learning geometrical concepts after the lessons were presented.	73	16	9	2	100
Average %		75	21	3	1	100

Table 5.2 shows the learner participants' reactions to the lesson when GeoGebra was used after the lessons they were taught using GeoGebra. The results indicated that 94% of the participants were very excited about learning the geometry of triangles through GeoGebra. The majority of the learners (81%) declared that they enjoyed the lessons. Moreover, the majority of the learners (77%) reported that they felt confident doing geometry activities based on the properties of triangles after they were taught using GeoGebra, so the general feelings of the learners were very positive regarding the use of GeoGebra as a pedagogical tool. Overall, the participants reacted favourably to the implementation of the knowledge by, and the skills received from their teachers from the training on the use of GeoGebra. Most of the learners (77%) were highly motivated, which signified a high level of satisfaction. The minority responses reflected in the table above were also quite important because they reflected the issue of indecisiveness. For instance, 30% were still unsure about the adoption of the new method of teaching and learning as compared to the common method of pencil and paper.

It also appears from Table 5.2 that, out of 76 responses, about 75% of the learner participants indicated that GeoGebra assisted them in enhancing their understanding of the properties of triangles. This result showed that the majority of the learners reacted favourably in terms of Level 1 (reactions) of Kirkpatrick's framework. Only 21% of the respondents were still unsure about their competence. About 3% of the learners indicated that they did not appreciate the use of GeoGebra and preferred the paper and pencil method, while on average, about 1% did not respond to some of the questions.

5.2.2 Parametric tests

Parametric tests such as t-tests, an analysis of variance, and regression rely on certain assumptions that need to be met before they are run (Patel, 2009). These assumptions are very important and if violated, the tests usually provide incorrect or unreliable results (Field, 2009; Öztuna, Elhan & Tüccar, 2006). Parametric tests assume that the data follow a particular distribution. This study used t-tests (independent t-test and dependent t-test or paired t-test) to analyse the data collected. The independent t-test was chosen since two dissimilar groups of participants were exposed to two different teaching methods. The paired t-test was also used because repeated-measures data were gathered over time from a single group consisting of the same people. When a researcher uses t-tests, the data needs to be approximately normally distributed within each group (Christensen et al., 2014; Field, 2014). If the assumption about the normal distribution is true, then the test is more likely to detect true mean differences or relationships that exist between the means of the experimental group and the control group. The next section discusses the t-tests used, outlines the assumptions of normality, and discusses how these assumptions were addressed in this study.

5.2.2.1 Independent t-test

This test is a parametric test that is used to determine whether the difference between the means of two unrelated groups is a statistically significant difference or if the means are different because of a sampling mistake. Unrelated groups, also called unpaired groups or independent groups, are two groups consisting of different participants in each group. Statistical significance represents the results of some statistical test that is being performed and refers to a claim that a result from the data generated by testing or investigation is caused by something other than the intervention. Researchers use a test static known as a p-value to establish whether an obtained result falls below the significant level, for instance .05, and if so, then that result is statistically significant. When the test result exceeds the p-value, the researcher accepts that there is no difference between two or more of the attributes under investigation. Otherwise, the opposite becomes true. The test uses a t-value calculated as follows (Field, 2009, p. 326):

$$t = \frac{\begin{matrix}\text{observed difference} \\ \text{between sample means}\end{matrix} - \begin{matrix}\text{expected difference} \\ \text{between population means} \\ \text{(if null hypothesis is true)}\end{matrix}}{\begin{matrix}\text{estimate of the standard error of the} \\ \text{difference between two sample means}\end{matrix}}$$

The *t*-value calculated is then compared to a *t*-distribution with a certain degree of freedom (*df*) in order to determine the significance level, denoted by α (p-value). The number of df is the number of values in the final calculation of a statistic (t) that are free to change. The df for the two independent groups are calculated by adding the number of participants in the two groups and then subtracting the number of groups. In the event that the researcher uses statistical packages such as the Statistical Package for Social Sciences (SPSS), the df is automatically computed while the α level is commonly set at $.05$, although it may vary. The α level or p-value gives the probability or percentage of making a mistake when conclusions are drawn.

This probability value (p) is found in the column marked *Sig* and if p is less than $.05$, then it can be concluded that there is a signifficant difference between the means of the two samples. This result means that there is less than 5% chance that the difference between the two means is due to chance. If p is greater than $.05$, it can be concluded that there is no statistically significant difference between the means of the two samples (Field, 2014). Once the *t*-value for the two unrelated groups is calculated, the researcher examines whether these *t*-values are large enough to assume that the difference found between the two groups is statistically reliable. This test was used to detemine if the means of the leaners taught the goemetry of triangles and quadrilaterals with GeoGebra and those taught with the traditional method were the same. This test was important because it was necessary to find out if learning with GeoGebra caused a change. This study used an alpha level denoted by an α of $.05$ and a 95% confidence interval for all statistical tests.

The independent *t*-test has the following assumptions (Field, 2014, p. 326):

1. Normally distributed data

   The assumption of normality claims that the sampling distribution of means is normal or that the distribution of means across independent samples is normally distributed (Field, 2014). Normality assumption of the sampling distribution can be assessed using graphs and statistical tests. However, to avoid doubts associated with the graphical methods when it comes to interpretations, normality tests need to be computed numerically using tests such as the Kolmogorov-Smirnov to substantiate the results obtained from graphical methods. Evidence from the literature has also shown that a researcher may not rely on graphs alone because merely observing how the distribution of data looks can be misleading (Öztuna et al., 2006). Öztuna et al. (2006, p. 172) state that:

> Graphical methods provide us with some information about the shape of the distribution, but do not guarantee that the distribution is normal and do not test whether the difference between the normal distribution and the sample distribution is significant.

In order to determine whether the difference between the means was normal or not, this study used histograms and box-plots. The histogram graphically provides a summary of the data, such as the centre of the data, the spread of the data and the presence of any outliers. Outliers are data points that differ significantly from other observations and their presence may lead to the incorrect conclusion, hence the need to be identified and excluded before statistical analysis is performed. If the data is normally distributed, the histogram will show peaked bars around the centre, while short bars pile up on either side of those in the middle, producing a symmetrical bell-shaped graph. A box-plot is another graph that shows a box with a line inside and has two lines known as whiskers that connect it to the minimum and maximum scores. In the box-plot, a normal distribution of scores is seen if the whiskers are approximately the same length, and if the line in the box is approximately in the middle of the box. If an assumption of normality is not met, the graphs will show more high than low scores or vice versa, showing that the distribution lacks the line of symmetry about the centre (Field, 2009; Morgan et al., 2011).

2. Interval data

Interval data is continuous data that can be measured in fixed units and the distance between each value is equal. In interval data, the data values can be added or subtracted, however the multiplication or division of data scores becomes meaningless. In this study, the assumption was met because the test scores (measured as numbers) received from the learner participants were used for analysis, and consecutive scores have equal differences.

3. Homogeneity of variance

The independent *t*-test assumes that the variances (also called dispersion) of the two unpaired groups that a research intends to measure are approximately equal in the population. When comparing the two groups, the way their data spreads out around the mean should be relatively equal. When a data set has a large value of variance, the values in the set are widely scattered; when it is small, the items in the set are tightly squeezed together. If the variances are unequal, the researcher is likely to reject a valid conclusion from the results obtained. The assumption of homogeneity of variance is tested using Levene's Test of Equality of Variances, which is produced in SPSS when the independent *t*-test procedure is run. This test provides a significance value (*p*-value), which the researcher can use to report whether the results are statistically significant or not. If the *p*-value obtained is greater than $.05$, Levene's test is non-significant, thus the group variances can be treated as approximately equal.

Alternatively, if the *p*-value is less than $.05$, Levene's test is significant, thus the groups have unequal variances, which is a violation of the assumption of homogeneity of variances and is normally caused by a small sample or by the violation of normality. This violation is corrected by increasing the size of the sample. However, if the data continues to violate normality despite increasing the sample size then this abnormality may be addressed by transforming the data or using non-parametric tests, which are not discussed in this study. If the variance is unequal across the groups, the data become overall skewed. This effect results in a reduction of the t-value and *df*, which then increase the *p*-value above the critical significance level of $.05$. This would not be the conclusion if the homogeneity of variances is not tested for.

4. Scores are independent

When a researcher wants to use the independent t-test, the scores of the participants from one group should not be influenced by the scores of participants from the other group. In other words, this test is used to test different groups of participants. In this study, this assumption was observed because the test scores came from two groups that were not related to each other. The two groups consisting of four schools split in half belong to two different circuits that are located far from each other and they remained in their research sites throughout the study.

5.2.2.2 Dependant $\boldsymbol{t}$*-test (paired* $\boldsymbol{t}$*-test)*

When the data from a group consisting of the same people is measured under two different conditions, this test is employed and it uses a t −value calculated as follows (Field, 2009, p. 327):

$$t = \frac{\bar{D} - \mu_D}{S_D / \sqrt{N}}$$

where $\bar{D}$ is the mean difference between the samples;

μ_D is the population mean; and

$S_D / \sqrt{N}$ is the standard error of the differences

This test is used to determine whether there is statistical evidence that the mean differences between two sets of paired observations is zero. Each subject is measured twice at different times, giving a paired set of observations, for example, a pre-test and a post-test with an intervention between the two time points. This test assumes that if the difference between the means is significant, then the intervention made a difference. If there is no statistically significant difference it means that the intervention did not make a difference. For instance, if a researcher is interested in evaluating the effectiveness of a training programme, the performance of the subjects is measured before and after receiving the training and then this difference is analysed using this test.

Like in the independent sample t-test, the results from this test lead to the conclusion that there is a significant difference between the means of the sample if the calculated value of t is less than $.05$ at $\alpha = .05$. If the calculated t-value is greater that $.05$, it can be concluded that there is no significant difference between the means. Since the same participants are used, the *df* is calculated by subtracting one from the sample size (*N*). This was used to determine the effect of GeoGebra on learner performance and to decide whether there was a significant difference between the means of the test scores.

The dependent t-test has the following assumptions (Field, 2014, p. 329):

1. Normally distributed data

This test is based on the normal distribution discussed in detail in the previous section, and assumes that the sampling distribution of the differences between the scores are normally distributed.

2. Data must be interval data

   As in the independent t-test, this test is appropriate when testing data that can be measured using an interval scale, which does not only show order and direction, but also the exact differences in the values. The data should be numeric and continuous. Continuous data take any integral value within a range, for example, test scores, height, weight and so on. The test scores used in this study conformed to this assumption.

5.2.3 Meeting independent samples t-test and paired samples t-test assumptions

Since pre- and post-tests are used for analysis, this sub-section discusses some of the pre-analysis issues related to the choice of the correct statistical procedure. To avoid making incorrect conclusions as a result of violating some of the assumptions, this section discusses the actions taken to justify the appropriateness of the statistical tests used and other procedures undertaken to achieve credible results. The conclusions from an independent samples t-test and paired samples t-test can only be trusted if assumptions of normality hold. Graphical methods employing histograms and box-plots were used to check whether the sampling distributions were normally distributed or not. The results from these graphs were confirmed using a Kolmogorov-Smirnov test to confirm normality.

5.2.3.1 Results from the graphical methods

In this study, the normality of the pre-test scores on the properties of triangles and quadrilaterals was verified by histogram and box-plots using SPSS IBM version 25. Figure 5.1 and Figure 5.2 show the histograms displaying the distributions of the results of the pre-tests scores, while Figure 5.3 shows the box-plots of the pre-tests results.

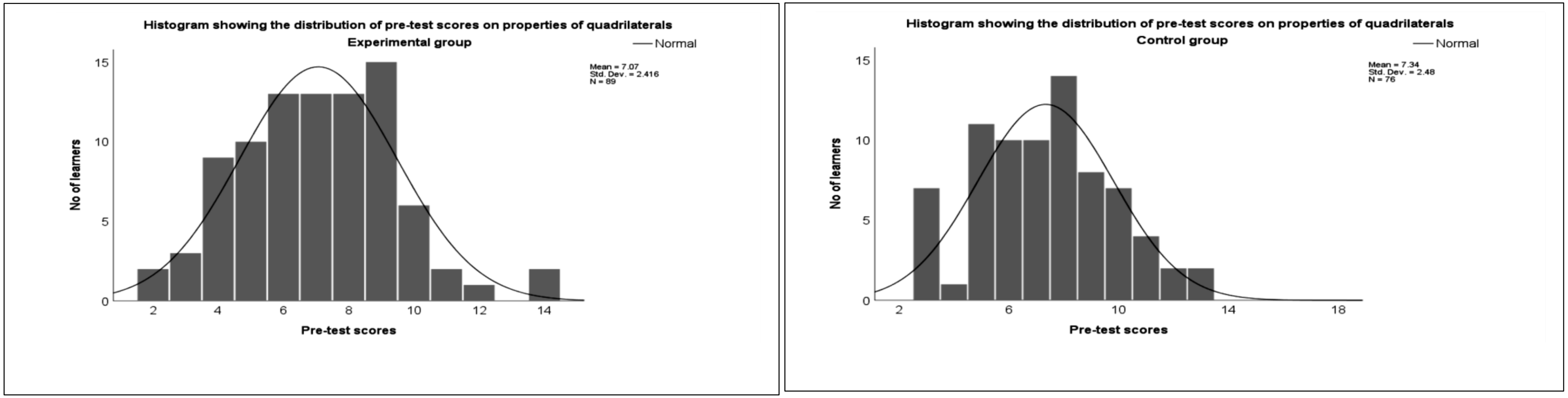

Figure 5.1: Histograms showing the distributions of the pre-test scores on quadrilaterals

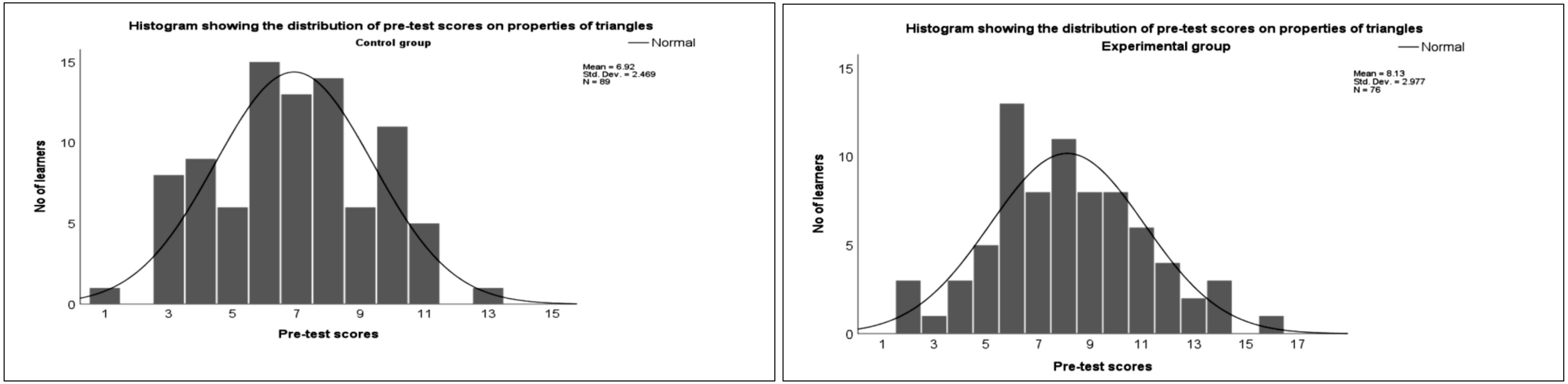

Figure 5.2: Histograms showing the distributions of the pre-test scores on triangles

The results displayed in Figure 5.1 and Figure 5.2 show that the sampling distribution is approximately normal, although one can see evidence of some possible deviations.

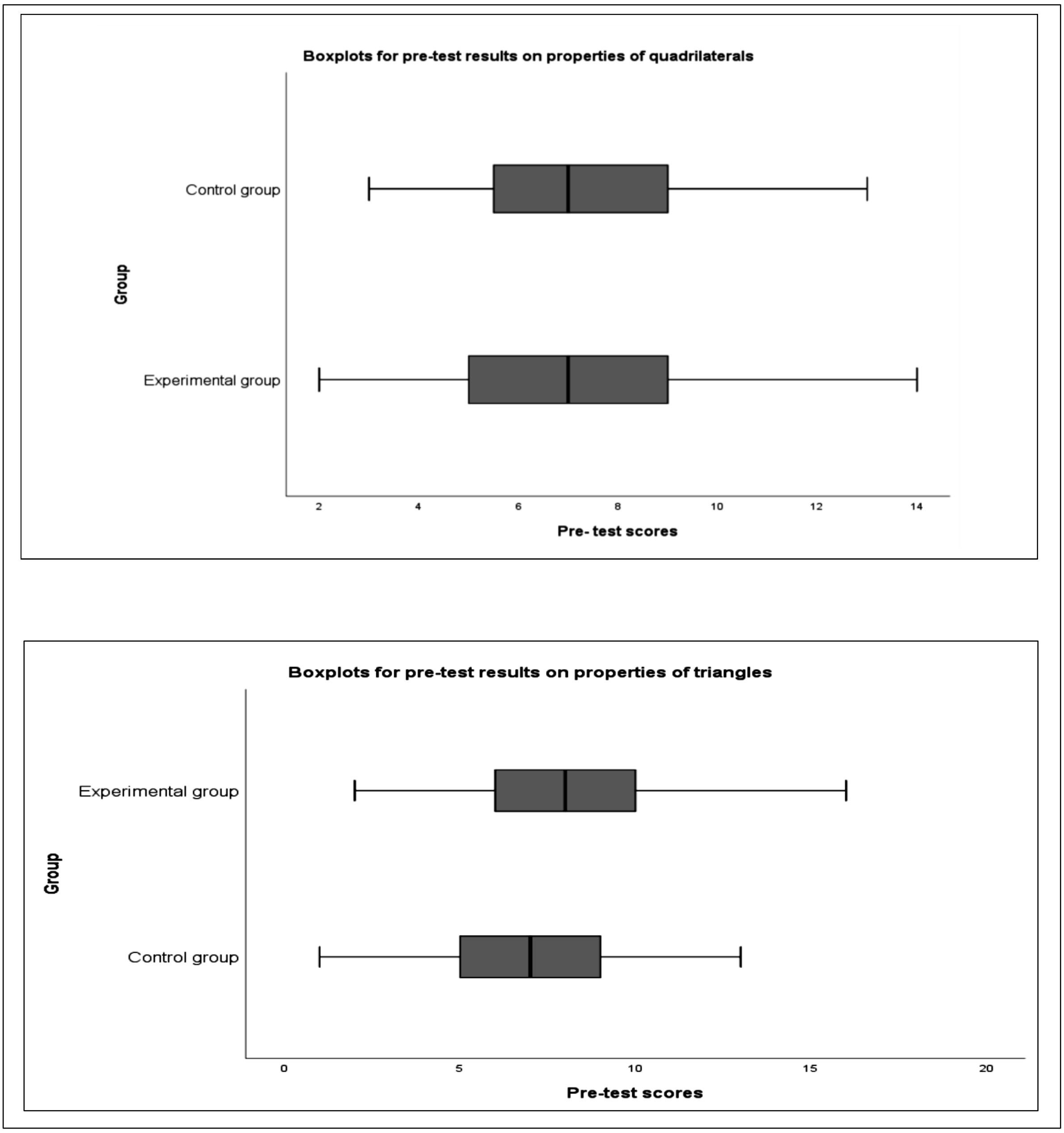

Figure 5.3: Box-plots of the pre-test scores on quadrilaterals and triangles

Figure 5.3 illustrates the results obtained from carrying out box-plots of the pre-test scores on quadrilaterals and triangles for both the experimental and control groups. To determine whether each distribution was normal, the researcher looked at the median for each box-plot. As seen by the shape of the distributions, the medians for both groups are positioned in the middle of each box, indicating symmetry. It can be concluded that the pre-test scores for the two groups are normally distributed. Furthermore, the two graphs indicate that there were no outliers in each group. These results from the histograms and box-plots demonstrate that the assumption on normality is not violated.

5.2.3.2 Results from the Kolmogorov-Smirnov tests

In order to confirm the results obtained from the graphical methods on testing for normality on the main dependent variable (achievement scores), these results were confirmed using the Kolmogorov-Sminorv test. This test was relevant in this particular case since the number of participants in both the experimental and control groups was above 30 (see Table 5.5). The Kolmogorov-Smirnov (K-S) test was used in order to conform to the requirement of the independent samples t-test and paired samples test. The Lilliefors significance correction was employed as we know that the K-S test uses this to provide a better and more accurate result. According to this test, if $p_{calc} > p_{table} = .05$, then normality is assumed. The following hypotheses were tested:

The null Hypothesis H_0: The two samples being tested come from the same distribution

The Alternative Hypothesis H_1: The two samples are from different distributions.

Table 5.3: Results from the Kolmogorov-Smirnov test on the pre-test scores on Quadrilaterals

	Group	Kolmogorov-Smirnov[a]		
		Statistic	df	Sig.
Pre-test	Experimental group	.088	89	**0.08**
	Control group	.093	76	**0.17**

a. Lilliefors Significance Correction

Table 5.4: Results from the Kolmogorov-Smirnov test on the pre-test scores on triangles

	Group	Kolmogorov-Smirnov[a]		
		Statistic	df	Sig.
Pre-test	Control group	.085	89	**0.15**
	Experimental group	.097	76	**0.08**

b. Lilliefors Significance Correction

As illustrated in Table 5.3, the pre-test scores on the properties of quadrilaterals for the experimental group, *D* (89) = .08, $p = .17$ ($p > .05$), and the control group, *D* (76) = .17, $p = .08$ ($p > .05$), were normal, indicating that the data were normally distributed in both groups. Also, Table 5.4 shows that the pre-test scores on the properties of triangles for the control group, *D* (89) = .15, $p > .05$, and the pre-test scores for the experimental group, *D* (76) = .08, $p > .05$, were normal, demonstrating that the data in both groups were normally distributed.

A summary of the results from the Kolmogorov-Smirnov tests for quadrilaterals and triangles are displayed in Table 5.5.

Table 5.5: Summary of the results from the Kolmogorov-Smirnov tests in both phases

Group	**1st Phase** Kolmogorov-Smirnov test $\alpha = .05$	**2nd Phase** Kolmogorov-Smirnov test $\alpha = .05$	**Number of participants ($N = 165$)**
Experimental (Grp 2)	$\boldsymbol{p = .08}$	[redacted]	$N = 89$
Control (Grp 1)	$\boldsymbol{p = .17}$		$N = 76$
Experimental (Grp 1)	[redacted]	$\boldsymbol{p = .08}$	$N = 76$
Control (Grp 2)		$\boldsymbol{p = .15}$	$N = 89$

Table 5.5 shows that 165 learners participated in the study and that the p-values in the two groups in each phase were greater than $.05$, demonstrating that the sampling distribution was normally distributed, which was not a violation of the assumptions of normality.

5.2.3.3 Results from the Levene's tests

It was also relevant to determine whether the two groups used in the study were comparable in terms of knowledge in the geometric concepts of triangles and quadrilaterals. Checking for similarity (equal variances) was done to ensure that any differences found in the dependent variable (test scores) were due to the independent variable (GeoGebra instruction) and not the inherent differences of the groups. This procedure ensured that whatever results obtained from the approved statistical test were practically valid. One group was taught with GeoGebra and the other group without GeoGebra. To establish whether the two groups were similar, a Levene's test and independent samples t-test were performed. A Levene's test was used to determine whether the two groups had equal variances or not, while the independent samples t-test was used to check if they were identical means. According to the Levene's test, if $p_{calc} > p_{table} = .05$, then the two groups are assumed to have equal variances and can be compared. After analysis, the Levene's tests on the pre-tests scores established that the two groups had variances. These results showed that there was no statistically significant difference between the two groups in terms of their knowledge base on geometric items before one was taught with GeoGebra and the other group without GeoGebra. These results indicated that the two groups were comparable. The following hypotheses were tested:

The null hypothesis H_0: The two groups compared had equal population variances.

$$H_0 : {\sigma^2}_1 = {\sigma^2}_2$$

The alternative hypothesis H_1: The two groups compared had an unequal population variance.

$$H_1 : {\sigma^2}_1 \neq {\sigma^2}_2$$

Table 5.6: The Levene's test and Independent Samples test for the pre-test scores on quadrilaterals

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Pre-test scores									
Equal variances assumed	.16	**.69**	-.72	163	**.47**	-2.75	.38	-1.03	.48
Equal variances not assumed			-.72	157.61	.47	-2.75	.38	-1.03	.48

For the pre-test scores on quadrilaterals given the homogeneity of variance by the Levene's test, $F(1, 163) = 2.00$, $p = .69$ ($p > .05$) was upheld, and a test assuming the equality of variances was calculated (see Table 5.6). The result of this test (see Table 5.6) indicated that there was no significant difference in the means $t(163) = -0.72$ and $p = .47$. These results suggest that the learners in the group with GeoGebra ($\mu = 6.76$, $\sigma = 2.77$) and the group without GeoGebra ($\mu = 7.07, \sigma = 2.42$) had the same conditions. The independent t-test for the equality of means indicates that the difference in the means was not significant given their respective deviations and p = .16. There was a higher mean for the group without GeoGebra, which, as indicated, was not significantly different from that of the group taught with GeoGebra. This indicated that there was no difference between the two groups of learners before teaching started on the geometric concepts of quadrilaterals and triangles. The assumption of equal variances was not violated, meaning that the two groups were similar (see Table 5.6). It was observed that the significance was above $.05$, implying that the condition of homogeneity was met. The following hypotheses were tested:

The null hypothesis H_0: The two groups compared had equal population variances.

$$H_0 : \sigma^2{}_1 = \sigma^2{}_2$$

The alternative hypothesis H_1: The two groups compared had unequal population variances.

$$H_1 : \sigma^2{}_1 \neq \sigma^2{}_2$$

Table 5. 7: Levene`s test and Independent Samples test for the pre-test scores on triangles

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Pre-test scores									
Equal variances assumed	2.11	**.15**	-2.85	163	**.08**	-1.21	.42	-2.05	-.37
Equal variances not assumed			-2.81	146.04	.08	-1.210	.43	-2.06	-.36

Given that the homogeneity of variance from the Levene's test, F(1, 163) = 2.11, p = .15 (p > .05), was upheld for the pre-test scores on triangles, a test assuming the equality of variances was calculated (see Table 5.7). The result of this test indicated that there was no significant difference in the means t(163) = -2.85 and p = .01. These results suggest that the learners in the group taught with GeoGebra (μ = 8.13, σ = 2.98) and the group taught without GeoGebra ($\mu = 6.92, \sigma = 2.47$) had the same conditions. The independent t-test for the equality of means indicated that the difference in the means was not significant. This indicated that there was no difference in the two groups of learners before teaching started on the geometric concepts of quadrilaterals and triangles. The assumption of equal variances was not violated, meaning that the two groups were similar (see Table 5.7). It was observed that the significance was above $.05$, implying that the condition of homogeneity was met.

5.2.4 Effect size

Although a researcher's calculated t −value is statistically significant, they need to check if the effect is practically significant. To find out if the effect is important, the researcher must calculate the effect size(s) that allow(s) for one to evaluate whether a statistically significant difference is substantive (Field, 2014, p. 332). Effect sizes are an objective measure of the importance of the effect. The effect sizes can be calculated for parametric tests, therefore, the following two formulas were used in this study:

1. For the independent t-test

In order to establish the magnitude of the difference between the mean values of the experimental and control groups, the effect size was computed manually using Cohen d\`s formula (Chilisa & Kawulich, 2012, p. 216):

$$d = |(\mu_1 - \mu_2)| / \left(\frac{(\sigma_1 + \sigma_2)}{2} \right)$$

where μ_2 - Mean of experimental group

μ_1 - Mean of control group

σ_1 - Std. Deviation of the experimental group

σ_2 - Std. Deviation of the control group

2. For the Paired t-test

The effect sizes (d) in paired Samples t-tests were calculated in SPSS using Cohen's d formula:

$$d = \frac{\mu_2 - \mu_1}{S\sigma_{x_2} - \sigma_{x_1}}$$

where $\mu_2 - \mu_1$ is the mean difference between post-test scores and pre-test scores.

$\sigma_{x_2} - \sigma_{x_1}$ is the standard deviation of the difference in scores.

Cohen (1988) suggests that:

d greater than or equal to 0.2 indicates a small effect size,

d greater than or equal to 0.5 indicates a medium effect size, and

d greater than or equal to 0.8 indicates a large effect size (Chilisa & Kawulich, 2012, p. 216).

5.2.5 Kirkpatrick's Level 2 (learning): learners' pre- and post-test results

To answer research Question 4: "*What is the impact of the use of GeoGebra on the learning that took place in the classroom?",* paired samples $t-$tests and independent samples $t-$tests were conducted to evaluate whether statistically significant differences existed between the mean achievement scores before and after the learners were exposed to GeoGebra instruction. In other words, the t-tests allowed me to test and find out if this difference (if any) was significant within a group (paired samples t-test) or across the groups (independent t-test). In this study, the paired samples $t-$tests were used within the same participants, while independent samples $t-$tests were used across the groups to determine the influence of GeoGebra usage as a pedagogical tool in each case.

Assumption testing indicated no gross violation of assumptions. Like in any statistical procedure, parametric tests have two competing hypotheses, the null hypothesis (H_0) and alternative hypothesis (H_1) . The null hypothesis states or assumes that there is no significant difference between the true means. The alternative hypothesis assumes that there is a significant difference between the true means. Hypothesis testing is utilised to enable us to make an inference (a logical judgement) from sample to population based on what the data is telling us rather than on the basis of direct observation. In other words, hypothesis testing assists one to reach "a conclusion that reflects on the likelihood of the researcher`s beliefs of what is true in the population" (Pietersen & Maree, 2015, p. 203).

5.2.5.1 Paired samples t-test for achievement tests within the group

To determine whether there was a change in the performance from the pre-test to the post-test, paired samples t-tests were used for those learners who were taught the geometry of quadrilaterals and triangles with GeoGebra (see Table 5.8 and Table 5.9). This test was found appropriate since the pre-test scores and post-test scores for the same participants were gathered at different times of the study.

a) *Paired samples t-test for the pre- and post-tests on the properties of quadrilaterals*

A paired samples t −test was performed to compare the means of the pre- and post-tests on the geometry of quadrilaterals. The following hypotheses were tested:

The null hypothesis was that there is no statistically significant difference between the means of the pre- and post-test results of the experimental group in the teaching of quadrilaterals:

$$H_0 : \mu_{pre-test} = \mu_{post-test}$$

The alternative hypothesis was that there is a statistically significant difference between the means of pre-posts-tests of the experimental group in the teaching of quadrilaterals:

$$H_1 : \mu_{pre-test} \neq \mu_{post-test}$$

Table 5.8: Paired samples statistics for the pre- and post-test scores on the properties of quadrilaterals

		Mean (μ)	N	Std. Deviation (σ)	Std. Error Mean
Pair 1	Post-test	13.72	89	2.50	.27
	Pre-test	7.07	89	2.42	.26

Table 5.9: Paired samples test for the pre- and post-test scores on the properties of quadrilaterals

	Paired Differences							
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1 Post-test – Pre-test	6.65	2.98	.32	6.02	7.30	21.08	88	**0.000**

A paired samples $t-$ test was conducted to evaluate the impact of GeoGebra usage on learners' scores in the achievement test. As illustrated in Table 5.8 and Table 5.9, there was a significant increase in achievement scores from the pre-test ($\mu = 7.07, \sigma = 2.42$) to the post-test ($\mu = 13.72, \sigma = 2.50$), $t(88) = 21.08, p < .001$ (two tailed). The effect size for this analysis ($d = 2.23$) was found to exceed Cohen's (1988) convection for a large effect ($d = .80$). The results above tell us that there was a significant increase of 6.65 in the mean score. In addition, it can be seen from the standard deviations that the variation in the data (i.e. spread of scores) is a little wider for the post-test scores ($\sigma = 2.50$) than for the pre-test scores ($\sigma = 2.42$). The high standard deviation value of 2.50 indicated that there is a bigger spread of the scores around the mean. Since the p-value $< .001$, the null hypothesis of equal population means was rejected in favour of the alternative hypothesis. It was concluded that the learners performed better after they were taught the properties of quadrilaterals with GeoGebra.

b) Paired samples t-test for the pre- and post-tests on the properties of triangles

To determine if there was a change in performance from the pre-test to the post-test, a paired samples $t-$ test was used for those learners who were taught the geometry of triangles with GeoGebra (see Table 5.10 and Table 5.11). The two hypotheses tested were given as:

The null hypothesis was that there was no statistically significant difference between the means of the pre- and post-tests of the experimental group in the teaching of triangles:

$$H_0 : \mu_{pre-test} = \mu_{post-test}$$

The alternative hypothesis was that there was a statistically significant difference between the means of the pre- and post-tests of the experimental group in the teaching of triangles:

$$H_1 : \mu_{pre-test} \neq \mu_{post-test}$$

Table 5.10: Paired samples statistics for the pre- and post-test scores on the properties of triangles

		Mean (μ)	N	Std. Deviation(σ)	Std. Error Mean
Pair 1	Post-test	14.89	76	2.04	.234
	Pre-test	8.13	76	2.98	.341

Table 5.11: Paired samples test for the pre- and post-test scores on the properties of triangles

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Post-test – Pre-test	6.76	2.77	.317	6.13	7.40	21.32	75	**0.000**

The results indicated in Table 5.10 and Table 5.11 show that there was a significant increase in the scores from the pre-test (μ = 8.13, σ = 2.98) to the post-test(μ = 14.89, σ = 2.04), $t(75) = 21.32$, $p < .001$ (two-tailed). In addition, one can see from the standard deviations that the variation in the data is a little wider for the pre-test scores (σ = 2.98) than the post-test scores (σ = 2.04). These results indicated that the learners performed better after they were taught the properties of triangles with GeoGebra. Specifically, these results show that when learners are taught with GeoGebra, their scores increase. The effect size for this analysis ($d = 2.45$) was found to exceed Cohen's (1988) convention for a large effect ($d = .80$). The researcher rejected the null hypothesis in favour of the alternative hypothesis, and as such it can be concluded that the results suggested that the learners' performance improved significantly when they were taught the properties of triangles with GeoGebra (See section 2.6).

5.2.5.2 Independent samples t-test for achievement tests across the groups

To confirm if there was any difference in the performance of the learners who were taught Euclidean geometry using GeoGebra, as compared to the group taught without GeoGebra, independent samples t −tests were conducted in each phase to evaluate whether a statistically significant difference existed between the mean achievement scores of the group taught with GeoGebra and the group taught without GeoGebra. Assumption testing indicated no gross violation of assumptions.

a) Independent samples t-test for the pre- and post-tests on the geometry of quadrilaterals

An independent samples t-test was used to compare the performance of those learners taught the geometry of quadrilaterals with GeoGebra with the performance of those taught without GeoGebra. The null hypothesis and alternative hypothesis tested were:

The null hypothesis was that there was no statistically significant difference between the means of experimental group and the control group:

$$H_0 : \mu_1 = \mu_2$$

The alternative hypothesis was that there was a statistically significant difference between the means of the experimental group and the control group:

$$H_1 : \mu_1 \neq \mu_2$$

It was important to determine whether the two groups formed from the four schools were similar in terms of their ability levels in geometric concepts involving the properties of triangles and quadrilaterals. Checking for comparability was vital since, as described in Section 3.6.2, there were some differences among the four schools with regard to the facilities available at each school. In the first phase of the study, Group 1 taught the properties of quadrilaterals without GeoGebra, while Group 2 taught the same content using GeoGebra. In the second phase, Group 2 taught the properties of triangles without GeoGebra, while Group 1 taught the same content using GeoGebra. At the end of the study, both groups had been exposed to GeoGebra as a teaching and learning strategy although on different topics.

In order to establish whether the two groups were the same in each case, an independent samples t-test and the Levene's test were conducted. The independent samples t- test was used to determine whether the mean of the experimental group was different from the mean of the control group. The Levene's test, alternatively, was used to establish whether the variances were the same or not.

Table 5.12: Group statistics for the post-test scores on the properties of quadrilaterals

PHASE ONE	Group	N	Mean	Std. Deviation	Std. Error Mean
Post-test scores	Experimental group	89	13.72	2.50	.27
	Control group	76	7.22	2.39	.27

Table 5.12 provides the descriptive statistics data about the experimental and control groups. These are the mean, standard deviation and the standard error mean for the dependent variable (post-test scores) of the two groups on the properties of quadrilaterals. The results indicated that the mean of the experimental group (μ = 13,72 σ = 2.50) was higher than the mean of the control group (μ =7.22, σ =2.39), giving a mean difference value of 6.50 (see Table 5.12).

Furthermore, it can be seen from the standard deviations that the variation in the data (spread of scores) is a little wider for the GeoGebra group ($\sigma = 2.50$) than the group without GeoGebra (σ =2.39. This meant that the scores were more closely clustered for the group that was not taught with GeoGebra versus the group that was taught with GeoGebra, but it does not show information concerning the statistical significance. To establish whether the differences in mean scores were statistically significant, an independent t – test was conducted.

Table 5.13: The Levene's and the independent samples test for the post-test scores

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Post-test									
Equal variances assumed	1.50	**.22**	17.00	163	**.000**	6.50	.38	5.74	7.25
Equal variances not assumed			17.06	160.89	.000	6.50	.38	5.74	7.25

An independent samples t-test was conducted to establish if the mean of the experimental group differed from the mean of the control group. The F test and the p value of the Levene`s test for the equality of variances were reviewed to establish whether the two group were similar. The Levene's test showed that the variances for the post-test scores were equal, F(1,163) = 1,50, p = .22. It appears from Table 5.13 that the results of this test were found to be statistically significant, $t(163)$ = 17.00, $p <$ .001 (two-tailed), indicating that the two groups were comparable. Overall, these results indicated that there was a statistical significant difference at the 5% level between the mean score in the two groups, that is, the data suggested that the mean post-test scores were different (since the p-value < 0.05). The effect size for this analysis ($d = 2.66$) was found to be more than Cohen's (1988) convection for a large ($d = .80$). The researcher rejected the null hypothesis in support of the alternative hypothesis, and concluded that the learners in the experimental group outperformed those from the control group in their understanding of geometry. This result indicated that the learners' level of knowledge and skills improved due to their exposure to GeoGebra instruction, implying that meaningful learning occurred (Kirkpatrick's Level 2).

a) *Independent samples t-test for the pre- and post-tests on the geometry of triangles*

In order to determine whether there was a change in the learners' performance from the pre-test to the post-test on the geometry of triangles, an independent samples t-test was done. This test compared the performance of the learners taught the geometry of triangles with GeoGebra with the performance of those taught with the traditional method. The null hypothesis and alternative hypothesis tested were:

The null hypothesis is that there is no statistically significant difference between the means of experimental group and the control group:

$$H_0 : \mu_1 = \mu_2$$

The alternative hypothesis is that there is a statistically significant difference between the means of experimental group and the control group:

$$H_1 : \mu_1 \neq \mu_2$$

Table 5.14: Group statistics for the post-test scores on the properties of triangles

PHASE TWO	Group	N	Mean	Std. Deviation	Std. Error Mean
Post-test	Control group	89	7.24	2.37	.25
	Experimental group	76	14.89	2.04	.23

Table 5.15: The Levene’s and independent samples test for the post-test scores

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Post-test									
Equal variances assumed	1.33	**.25**	-22.04	163	**.000**	-7.66	.35	-8.35	-6.97
Equal variances not assumed			-22.29	162.98	.000	-7.66	.34	-8.34	-6.98

An independent samples t-test was conducted to compare the post-test scores of the learners taught with GeoGebra and the learners taught without GeoGebra. In Table 5.15, the Levene's test shows that the variances for the post-test scores were equal, F(1,163) = 1,33 p = .25. Based on Table 5.14 and Table 5.15, the result of this test was found to be statistically significant, $t(163)$ = -22.04, $p <$ .001 (two-tailed). These results indicated that there was a statistically significant difference in the scores of the experimental group ($\mu = 14.89, \sigma = 2.04$) compared to the control group ($\mu = 7.24, \sigma = 2.37$) at 0.05 level of significance ($t(163)$ = -22.03, $p <$ .001). In addition, one can see from the standard deviations that the spread of scores is a little wider for the group without GeoGebra ($\sigma = 2.37$) than the group with GeoGebra ($\sigma = 2.04$). The magnitude of the differences in the means was large ($d = 2.69$). The null hypothesis was rejected in favour of the alternative hypothesis, and it was concluded that the learners taught with GeoGebra performed better than those taught without GeoGebra since the p value was less than .001. This indicated that the learners experienced significant growth in their learning progression after being exposed to this technology-mediated learning environment. In other words, there was an improvement of performance – learning took place, as found in Kirkpatrick’s Level 2 – and it was due to GeoGebra. Results are consistent with past studies reviewed (see sections 2.6 and 2.7).

5.3 CHAPTER SUMMARY

This chapter focused on the learners’ reaction (Level 1) to lessons they were taught using GeoGebra and its impact on their performance in terms of Level 2 of Kirkpatrick’s framework.

The data gathered through a learner questionnaire and the pre- and post-tests were presented and analysed using quantitative methods.

Level 1 (reaction):

The reaction questionnaire comprised questions intended to obtain some sense of how the learner participants felt towards the lessons taught with GeoGebra. Learners' responses in the reflection questionnaires revealed that the majority of the learners were excited about learning with GeoGebra and enjoyed GeoGebra tuition. The learners, in general, reacted positively to the lessons presented with GeoGebra. These positive answers would seem to suggest that the learners enjoyed a positive learning experience. This new teaching and learning tool allowed learners to collaboratively investigate the properties of triangles and quadrilaterals. A majority of the learners pointed out that GeoGebra usage in geometry learning enhances understanding of geometric concepts, hence, they perceived it as a useful tool for learning geometry. The whole process of inquiry promoted an increase in conceptual understanding of the geometry of triangles and quadrilaterals in a GeoGebra-based environment.

Level 2 (learning):

The results from the pre- and post-tests showed that the learners taught with GeoGebra outperformed the learners taught without GeoGebra. The significant improvement in learners' performance showed that the implementation of GeoGebra by teachers newly trained therein resulted in learners' improved knowledge of geometry content and the required skills in handling questions involving geometric concepts. The positive feelings displayed by most of the learners contributed to their enhanced learning (Level 2), suggesting a causal relationship between reaction and learning (Kirkpatrick, 1994; Kirkpatrick & Kirkpatrick, 2010). Although, these results support the assertion of causal linkages by Kirkpatrick (1994) and Kirkpatrick and Kirkpatrick (2010) that a positive reaction (Level 1) by participants results in learning (Level 2), the literature contests this assumption (Alliger & Janak, 1989; Alliger, Tannenbaum, Bennett, Traver & Shotland, 1997; Bates, 2004; Ebner & Gegenfurtner, 2019; Holton, 1996; Warren, Allen & Birdi, 1999) (see Section 2.9.2). According to the results, the training programme on the use of GeoGebra in practice was found to be effective at both levels, even though the reaction was unrelated to learning (Holton, 1996).

The next chapter presents a discussion of the results, conclusions and recommendations emanating from the gathered information.

CHAPTER 6 SUMMARY, CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

This chapter provides a summary of the results from the data analysis and discussion section with the intention of drawing conclusions that provide answers to the main research question. The results cannot be generalised to the rest of the population, nonetheless, they will provide the relevant stakeholders with evidence from the research that may be useful in their respective fields. Additionally, they will contribute to future research in related fields that it has not been possible to include in this study, but which are necessary to examine. Section 6.2 will provide a detailed summary of the study. Section 6.3 will provide a summary of the key results from the study. Section 6.4 will review the significance of the results and in Section 6.5, the contribution of the research will be provided as well as an indication of the new knowledge generated. The limitations of the study will be identified in Section 6.6, while the recommendations based on this study will be presented in Section 6.7. The chapter and research study will be concluded in Section 6.8, while a summary of the chapter and the final word are provided in Section 6.9.

6.2 SUMMARY OF THE STUDY

This study was implemented with the intention of searching for answers to the main research question stated in Section 1.5 as: *How does the implementation of GeoGebra by teachers newly trained in its use influence their classroom practice, as well as learner experience and achievement in the geometry classroom?* In the process of obtaining answers to the main research question, the following sub-questions guided this study:

1. *How did the teachers react to their training in the use of GeoGebra?*
2. *How did the teachers implement their training in the classroom?*
3. *How did the learners react to the use of GeoGebra in the classroom?*
4. *What is the impact of the use of GeoGebra on the learning that took place in the classroom?*

This study investigated how the implementation of what was recently learnt by newly-trained teachers in the use of GeoGebra influenced their classroom practice. The study also explored the impact of this implementation on learner experience and achievement. Specifically, I evaluated the effectiveness of the training in GeoGebra usage as an instructional tool by using Kirkpatrick's framework. I specifically looked into how its use in practice changed the learners' outcomes in geometry. The literature study in Chapter 2 showed that the majority of studies done involving GeoGebra software focused on well-equipped schools beyond South African borders. In the South African context, numerous rural schools do not have computer laboratory facilities in comparison to urban schools, and relatively few schools are fully furnished with functional computer facilities. Multiple sources were used to collect qualitative and quantitative data.

The qualitative data gathered from the post training questionnaire, observations and post-training interviews were manually coded and analysed in Chapter 4 in terms of two of Kirkpatrick's levels of evaluation, namely, reaction and behaviour. The aim was to investigate the teachers' satisfaction by collecting information about how they felt about the training and whether they were able to transfer the knowledge, skills and attitudes learnt to reflect positive behavioural change. Alternatively, an analysis of the collected quantitative data was conducted using descriptive statistics and t-tests, as expounded on in Chapter 5, to assess the changes in learners' knowledge, understanding and cognitive skills in terms of geometry and their reactions. This was done using SPSS software.

More specifically, as discussed in Chapter 5, the extent to which the learners learnt as a result of using GeoGebra in the classroom (Kirkpatrick`s Level 2) was tested. Descriptive statistics were used to describe the means and variances of the pre- and post-tests, while the percentages summarised individual choices for different items in the learner questionnaires. Inferential statistics using t-tests were used to compare the means and test for the difference between the two means of the pre- and post-tests within the group and between the groups. Two analysing strategies were used to draw conclusions taking into consideration the research questions and the theoretical framework guiding this study. The next two sections present a summary of the main findings in terms of the research questions.

6.3 RESPONDING TO THE RESEARCH QUESTIONS

6.3.1 Sub-question 1: How did the teachers react to their training in the use of GeoGebra?

The purpose of this question was to investigate teachers' reaction to their training in terms of Kirkpatrick's Level 1. All of the trained teachers were confident about the use of GeoGebra for teaching and learning, although their levels of confidence were not the same, as shown by their different abilities when implementing it in their classrooms. They indicated that they enjoyed the training. Moreover, they felt motivated and were willing to engage in further workshops that focused on teaching and learning with GeoGebra or any other relevant educational technologies. Overall, the teachers were positive about the impact of GeoGebra on the performance of learners, praising the power visualisations and the dynamic nature of the software. The literature provided support for this research result (see Section 2.2 and Sub-section 2.7.2). However, the teachers had reservations about the full-fledged implementation of GeoGebra, citing a lack of resources and support from principals and Subject Advisors (SAs) as major factors. Both the literature and the participants confirmed that challenges exist in teaching and learning using educational technologies such GeoGebra in rural schools (see Section 2.1.2).

People's motivation and attitudes toward a new idea are associated with judgments regarding one's abilities to perform a given task or handle future situations that determine future behaviour. If the participants had not bought into the relevance of the training programme and its content, they would feel less able to implement the necessary changes. Thus, new thoughts that individuals view as worthwhile during or after training stand a good chance of being transferred into desired change in behaviour (Kirkpatrick & Kirkpatrick, 2010).

6.3.2 Sub-question 2: How did the teachers implement their training in the classroom?

In order to describe the teachers' ability to transfer knowledge and skills (change in behaviour) as they taught the properties of triangles and quadrilaterals, the classroom observations focused mainly on: 1) How the teachers planned and prepared the learning environment, 2) How they demonstrated CAPS-aligned, pre-constructed activities, including strategies for applying appropriate GeoGebra tools to enhance learning and creativity in learners, and 3) How they used GeoGebra to facilitate a variety of effective assessment and evaluation strategies. All four teachers managed to implement GeoGebra-instructed lessons. Teacher 2 showed the highest competency in using GeoGebra to facilitate learning and teaching in the classroom, followed by Teacher 1. Teachers 3 and 4 showed the least proficiency in their ability to demonstrate their knowledge and skills learnt during training (see Section 4.4). These results were drawn from the analysed data from the questionnaires and pre- and post-intervention interviews (Section 4.2.1 and 4.2.2).

The satisfaction, knowledge and skills acquired by participants in a training programme are important for successful change implementation. The study found that the acquisition of topic-related knowledge and skills, and a willingness to put the new knowledge (idea) into practice may result in changed behaviour, indicating that positive reaction has a positive influence on change in behaviour. That is, the more people know about a new thought, which in the context of the study is the teaching and learning of geometry with GeoGebra, the more likely it is that they will implement it. This result is consistent with the findings from Heydari, Taghva, Amini and Delavari (2019) and Smidt, Balandin, Sigafoos, and Reed (2009) (also see Section 2.3).

6.3.3 Sub-question 3: How did the learners react to the use of GeoGebra in the classroom?

Most of the learners (82%) agreed that the use of GeoGebra significantly improved their knowledge and cognitive skills in terms of the properties of quadrilaterals, and 74% from the other group who were taught the properties of triangles with GeoGebra also confirmed the same results. The majority of the learners reacted favourably towards learning with GeoGebra, showing that they appreciated its use as compared to the traditional method of paper and pencil. This result is consistent with what Kirkpatrick (1996) says about the importance of positive reaction as he emphasises that even though positive reaction does not ensure learning, negative reaction reduces the chance of learning (see Section 2.7.2). These results show that when learners become happy about a new learning strategy, they are likely to support the new innovation, which in turn motivates them to learn. This increases the chance of improving their performance in the process.

6.3.4 Sub-question 4: What is the impact of the use of GeoGebra on the learning that took place in the classroom?

An analysis of the data from the pre- and post-tests indicated that the learners from the experimental group outperformed those from the control group in Phases 1 and 2. In Phase 1, the experimental group obtained a mean of 13,72 as compared to the mean of the control group with 7,22 in the geometry of the properties of quadrilaterals with an effect size of 2,66. Similarly, in Phase 2, the experimental group yielded a mean of 14,89 compared to the control group with a mean of 7,24 in the geometric concepts of the properties of triangles with an overall effect size of 2,69. Therefore, it appears that the GeoGebra-mediated lessons resulted in improved learner performance in comparison to the traditional chalk, talk and write method (see Section 4.5.1.5). To facilitate a change, teaching with powerful instructional tools such as GeoGebra could enhance teachers' perspectives regarding the impact it may have on learners' learning. The results from the literature supported this result (see Section 2.6).

The approach to training transfer proved to be a very useful framework in investigating the influence of technology-mediated teaching and learning approaches on learner achievement. In this study, the results showed the statistically significant effect of GeoGebra instruction on the overall performance of learners in comparison to the performance of learners taught without GeoGebra, despite unfavourable school-specific teaching and learning environments. This finding presents implications for the field of education that promote the use of GeoGebra as a means of improving the teaching and learning of geometry at high school level. In other words, learning through GeoGebra is considered to be better than learning without GeoGebra because the results of this study show that the success of teaching with GeoGebra is higher as compared to that of teaching without GeoGebra.

6.3.5 The main research question

How does the implementation of GeoGebra by teachers newly trained in its use influence their classroom practice, as well as learner experience and achievement in the geometry classroom?

This study was conducted to investigate how the teachers' training experiences in GeoGebra usage influenced learner achievement in geometry. The training impacted positively on the performance of the learners in geometry when GeoGebra was implemented in the classroom by the newly trained teachers. Shawer (2018) obtained similar results in a study regarding the positive training experiences and learning outcomes of learners. They confidently applied the skills and utilised the knowledge learnt from GeoGebra training, although with varying degrees of competency. Lastly, a trainee's satisfaction with a programme may result in the acquisition of knowledge, skills and attitudes, which in turn could lead to the successful implementation of the programme/software, possibly contributing to an increase in learner performance (see Sections 2.2 and 2.3). Thus, the findings of this study allow one to understand the hierarchical nature of Kirkpatrick's model, which is consistent with results from Aziz (2016) and Rafiq (2015).

6.4 SIGNIFICANCE OF THE RESULTS

The evidence from this study suggests that the use of GeoGebra as a tool for instruction has the potential to increase the performance of learners significantly. The results are consistent with the findings of related literature, such as the work of Dogan and Icel (2011); Gweshe and Dhlamini (2015); Masri et al. (2016); Özçakır, Aytekin, Altunkaya and Doruk (2015) and Shadaan and Leong (2013). The findings indicate that large effect sizes are achievable when GeoGebra is used for instructional purposes in classes that are under-resourced as long as teachers are positive and eager to implement the teaching and learning approach.

6.5 CONTRIBUTION OF THE RESEARCH

The findings presented in this study show that despite schools being situated in rural areas, learners benefit from being exposed to free software like GeoGebra when learning Euclidean geometry. Thus, the findings suggest that GeoGebra`s ability to provide multiple representations can help learners to understand geometric concepts when integrated into the curriculum. A wide gap is still evident in non-fee paying, quintile 1-3 schools situated in remote and rural areas where learner performance has remained very low in mathematics. The study has gone some way towards enhancing our understanding of how trained teachers' implementation of GeoGebra in the classroom (after training in its use) can change learner achievement. Although the theoretical framework indicates different competency levels in terms of how GeoGebra was implemented, the results indicated that the teachers' positive stance and willingness to implement educational technologies can result in improved learner performance irrespective of poor learning environments. A gap was identified in the literature and this study consequently led to the generation of new knowledge. The new knowledge attained is that GeoGebra, as a pedagogical tool, can work effectively in deep rural schools where geometry is hardly taught.

6.6 LIMITATIONS

This study was limited to only Grade 10 mathematics teachers and learners from the Ehlanzeni District in the Mpumalanga Province, which does not allow for the generalisation of the results. A larger sample size covering more schools within the province or across the provinces of the organisation would help in generalising the findings. As already discussed, the purpose of this study was to investigate how the implementation of GeoGebra by newly trained teachers in its use influenced their classroom practice. The impact of this implementation on learner experience and achievement was also explored. Another limitation was that this study did not control the demographic variables of the teachers such as their age, gender, income, and hierarchical position, and it should be noted that these may have influenced the trainees' experiences and evaluation of the training they received. For instance, the sample of this study consisted of males only, therefore, regarding the gender representation of the sample, the non-involvement of female participants may limit the integrity of the results when gender balance is taken into account. Consequently, the gender bias may have had some effects on the quality of the results.

One of the limitations in this study could also be due to the Hawthorne effect as a result of my presence in the classroom during lesson observations. The impression that someone is present to observe them teach may have caused the teachers to change or modify their behaviours simply because they became aware that they were being observed. This sudden change in some aspects of behaviour (the observer effect) may have compromised the integrity of the data gathered. I tried at all times to avoid interfering with the lesson proceedings by remaining quiet and focusing on recording what I observed taking place throughout the lesson. I only moved around when I wanted to record a video or take pictures of the lesson under observation.

In order to minimise subjectivity throughout the study, all of the data collected from the participants were shared and discussed with the participants, other post-graduate students, my supervisor and co-supervisor to ensure that the conclusions drawn represented the original views of the participants. The fact that only four lessons (one per teacher) were observed is another limitation because it is possible that what was obtained during the observed lesson for each teacher may not have been what would have been obtained over a longer period of time. In reality, observing a teacher teaching for less than an hour may not give one a reliable picture of what normally takes place in the mathematics classroom, to some degree. For instance, some learners may not participate and decide to remain silent to avoid embarrassment in front of the other learners when they give the wrong answers in the presence of a visitor. As a result, the daily situations that the teacher deals with may not prevail in the observed lesson, resulting in gathering data that may not give a true reflection of what may have transpired in the researcher's absence.

6.7 RECOMMENDATIONS

The following recommendations are divided into two sections: the first section offers recommendations providing suggestions for future researchers in the endeavour to further the scope of this study. The second section presents a set of recommendations for policy and practice. All recommendations suggested are based on the results of this study.

6.7.1 Recommendations for further research

This study provided the first step towards the evaluation of the effects of training and experience on mathematics teachers in the use of GeoGebra. This section presents recommendations for additional studies. The study was conducted on a small scale, therefore it is recommended that a similar study be conducted using a bigger sample consisting of schools that have the same characteristics but from other provinces in order to yield results that can be generalised. The duration of the teachers' training (one day per group) may be considered to be insufficient to provide full evidence of the teachers' growth in all three levels of evaluation. As such, it is recommended that further studies be carried out with a prolonged training time in order to evaluate the effectiveness of GeoGebra software in teaching geometry.

Since this study focused on the geometry of triangles and quadrilaterals only, there is a need for more experimental studies about the teachers' experiences in the use of dynamic geometry software, i.e. GeoGebra, and an examination of its influence on learners' achievement in various geometric concepts and even other topics in mathematics. This study also suggests that future research should incorporate questions that address trainee expectations about the programme and how their expectations about the program were met. The study further suggests the need for better integration of the work environment and individual characteristic variables in Kirkpatrick's model to better understand training effectiveness. In addition, further studies could be conducted to analyse the implementation of Level 4 (results) of the evaluation, which was not included in this study.

6.7.2 Recommendations for policy and practice

Based on the findings of this study, three recommendations for policy adjustment have been identified to improve the situation at hand. First, it is suggested that the DBE officials responsible for providing training to teachers could consider re-designing the training programmes. A gap may exist between the intended curriculum according to the e-Education policy and what the teachers practice at work. As such, it is proposed that the training programmes intended to improve in-service teachers' pedagogical skills should focus on appropriate knowledge and skills that are linked to technological innovations such as GeoGebra. In other words, more attention is currently given to theory but there is a need to promote quality teaching and learning through investigating and examining what is happening in practice when it comes to technology integration in rural schools.

Second, policy makers and all stakeholders could contribute to the curriculum to assist rural teachers to include the use of GeoGebra in mathematics in an attempt to reduce a technological gap between teachers, learners and the teaching of mathematics. GeoGebra could be considered to be a better alternative for rural schools according to the results from this study where the reality of gaining internet connections is still far-fetched because it can be used without connecting to the internet. Third, it is also suggested that the officials in charge of training programmes on the use of technologies evaluate the effectiveness of the training workshops in order to identify areas that need improvement. Teachers must be given the opportunity to report if they are in need of additional support so that the relevant knowledge, skills and attitudes may be transferred through further training.

6.8 CONCLUSION

This study was a first attempt to engage in an extensive evaluation system to assess a training programme in rural schools. The objective was to provide a fully implemented study to investigate the first three levels of Kirkpatrick's model as they relate to a training programme on the use of GeoGebra in the teaching and learning of the geometry of triangles and quadrilaterals. The results of the study show that teachers in rural schools can effectively transfer knowledge learnt from a training programme on the use of GeoGebra in the teaching and learning of geometric concepts better as compared to their colleagues from the same rural environment who use the traditional classroom teaching method. At the same time, it appears that the learners taught with GeoGebra performed better than those taught without GeoGebra. That is to say, the results from this study have shown that GeoGebra instruction can work effectively in deep rural schools where geometry is, in some cases, not taught by teachers.

6.9 SUMMARY

The discussions on the findings have been carried out with respect to what they have added to the body of knowledge, most notably that the teacher participants were positive and willing to implement GeoGebra in their classrooms after the training, despite a lack of facilities in their schools. The discussions also showed that the teachers' positive reaction towards the training and their ability to implement their knowledge and skills (changed behaviour) acquired during their training in GeoGebra usage resulted in improved learner achievement. Thus, conceptual growth in the learners was observed to improve after exposing them to GeoGebra lessons, which is consistent with the reviewed literature.

Final word

In closing, it must be said that mathematics teachers should be well trained in pedagogical strategies aligned with educational technologies that are relevant to 21st century learners. Without such teachers, mathematics classrooms are little more than mere buildings. If in-service training programmes for teachers continue without attracting the best models for training evaluation, there will not only be a deficit of expert teachers pedagogically, but the teachers available may not utilise the best teaching practices. Our mathematics learners will suffer at the hands of such teachers. And when these learners suffer, the future of the whole nation will suffer too. Albert Einstein once said "I never teach my pupils. I only attempt to provide the conditions in which they can learn" (Walter & Marks, 1981, as cited in Hansen, 2000, p. 24). For teachers, this suggests that they must strive to play the role of a facilitator rather than telling learners everything because the latter approach promotes rote learning instead of discovery learning. I hold the belief that lifelong learning takes place when a learner is motivated to learn from within and attempts to learn something on his/her own. As an agent of change in the classroom, the most effective teacher enhances effective learning by allowing learners to be actively involved in knowledge construction while his/her role is to provide support where needed.

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APPENDICES

APPENDIX A: A POST-INTERVENTION TEACHER QUESTIONNAIRE

Specific to GeoGebra technology

The following instrument was used by (Riales, 2011) in a study on An Examination of Secondary Mathematics Teachers` TPACK Development Through Participation in a Technology-Based-Lesson Study. For the purpose of this study, I have modified this instrument to meet my needs. The purpose of this questionnaire seeks to obtain information on your training experiences in the use of GeoGebra in the teaching and learning of grade 10 Euclidean geometry after participating in the training programme.

For official use only
1. Section trained on using GeoGebra:
Geometry of triangles ☐ | Geometry of quadrilaterals ☐
2. Code name: T1 ☐ T ☐ T3 ☐ T4 ☐ | T 5 ☐ T 6 ☐ ☐

SECTION A

Please use (**X**) to indicate your chosen answer (response) that describes your beliefs and experiences during training on use of GeoGebra in the teaching of geometric concepts.

A: What are your feelings after going through the training in the use of GeoGebra?

Key for your responses
SA = Strongly Agree
A = Agree
UN = Uncertain
D = Disagree
SD = Strongly Disagree

A. Self-evaluation on competence to use GeoGebra software after training

		1	2	3	4	5
		SA	**A**	**UN**	**D**	**SD**
1.	I feel competent to use GeoGebra in the classroom.					
2.	I am motivated to use GeoGebra in class because it saves time.					
3.	GeoGebra training has equipped me with confidence and understanding to teach geometric concepts in my classroom.					
		1	**2**	**3**	**4**	**5**

		SA	A	UN	D	SD
4.	I intend to use GeoGebra frequently in my classroom when teaching geometric concepts.					
5.	My experience with GeoGebra has given me insight into the importance of integrating technology in geometry lessons.					
6.	I intend to use GeoGebra software to develop more new activities for teaching other geometric concepts.					

SECTION B

B: As a teacher who has undergone training on how to use GeoGebra, what do you think would be the use and benefits of GeoGebra to your learners` achievement/learning? Thus, how do you perceive the usefulness of GeoGebra from you training experiences?

Use the rating scale provided to indicate your responses using (**X**).

B. Self-Perceived usefulness of GeoGebra after training						
		1	2	3	4	5
		SA	**A**	**UN**	**D**	**SD**
7.	GeoGebra leads to better understanding of geometric concepts by the learners.					
8.	The use of GeoGebra software in the classroom saves time.					
9.	Use of GeoGebra will help the learners to visualize the connections between different domains of geometric concepts with ease.					
10.	I believe this technology would improve learners` achievement/learning.					
11.	I am convinced that this technology is essential to promote conceptual learning for my learners.					
12.	I believe that if my learners are exposed to GeoGebra too often, they will learn the geometry for themselves.					
13.	I believe my learners can learn how to do geometry on paper first, and then they can be exposed to use of this technology.					
14.	I am convinced that GeoGebra as a learning tool enables learners to engage in high-level thinking activities in geometry.					

SECTION C

C. **Additional information on training experiences and perceived usefulness.**

1. Do you think GeoGebra software will be useful in your own school and classroom environment?

   Give a brief explanation based on your own beliefs/opinions in the space provided below.

   ……………………………………………………………………………….

   ……………………………………………………………………………….

   ……………………………………………………………………………….

   ……………………………………………………………………………….

2. Based on your training experiences, what other factors do you think may aid or hinder the use of GeoGebra? Use the space below.

   ……………………………………………………………………………….....

   ……………………………………………………………………………….

   ……………………………………………………………………………….

   ……………………………………………………………………………….

3. Overall, how do you think your training experiences may influence your learners` achievement/learning?

   ………………………………………………………………………………

   ………………………………………………………………………………

   ………………………………………………………………………………

   ………………………………………………………………………………

Thank you for taking part.

APPENDIX B: POST- TRAINING TEACHER INTERVIEW

Our main goal for engaging you in this training programme was to assist you with training on how to teach Euclidean Geometry in Grade 10 using GeoGebra. The programme also intended to help you with knowledge and skills on how to develop technology-related lessons by creating GeoGebra offline Activities to use in your Mathematics geometry class. The purpose of this interview is to gather knowledge about your experiences during the intervention period. The interview session will take less than 30 minutes of our time. All responses from you shall be used for academic purposes only. This means that your responses will remain confidential and the report will not identify you as the respondent in any way.

1. As mathematics teacher how did the technology you learnt empower you with the skills you can use in your mathematics class from now onwards? You may give specific examples
2. How was your experience throughout the training programme in learning how to teach with GeoGebra?
3. Please identify any specific difficulties/challenges you met when you were learning how to use GeoGebra.
4. What would you recommend in order to address the challenges you experienced when you used GeoGebra?
5. What is your view of the role of GeoGebra in the teaching and learning of mathematics? Has your view of the use of GeoGebra changed after the training intervention?
6. Do you feel adequately trained to use GeoGebra in your mathematics class from now onwards?
7. If your answer is no, what do you suggest to improve on future training intervention workshops?
8. What is your confidence level in the use of GeoGebra as a teaching and learning tool in Euclidean geometry by yourself?
9. How has your participation in this training programme influenced your future plans in attending workshops/ and or professional training programs that involve use of educational technology in teaching and learning of Euclidean geometry?
10. In conclusion, what would be your recommendations to other mathematics teachers about GeoGebra?

Thank you for your taking part in this interview

APPENDIX C: PRE-TEST AND MEMORANDUM

PRE –TEST (Grade 10: Geometry of triangles and Quadrilaterals)

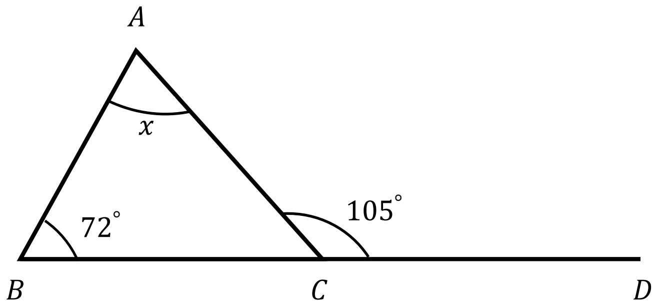
Instructions:

1. Read each question carefully.
2. Answer all the questions on the answer sheet provided.
3. Mark using (**X**) the correct letter with a pencil in the grid paper provided.
4. This test consists of section A and B.
5. There is only one correct answer in each question in **ALL** sections.
6. All diagrams and sketches are **NOT** drawn to scale
7. The test has a total of **40** marks and is **1**-hour long.

SECTION A: Geometry of triangles **20 marks**

PART 1:

1. In the diagram below, what is the value of x? (1)



A. 33 B. 75 C. 147 D. 162

2. An isosceles triangle is a triangle with the two sides of equal length.

   Which is **TRUE** in every isosceles triangle? (1)

   A. The three sides must have the same length.

   B. One side must have twice the length of another side.

   C. There must be at least two angles with same measure.

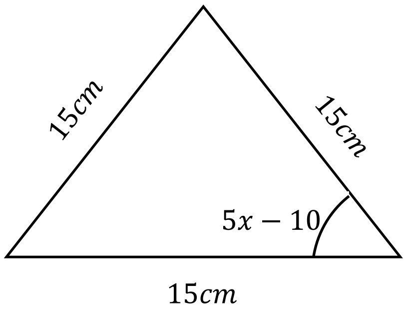
   D. The three angles must have the same measure.

3. Choose the correct word or phrase that makes the following statement true.

   In an equilateral triangle, a line drawn from the any vertex perpendicular to any side of the triangle ________________ the side. (1)

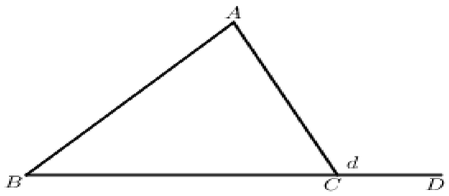
   A. Is adjacent to B. Bisects C. Is parallel to D. Is the base of

4. Given the triangle below, what is the value of x in the triangle (1)



A. 5 B. 10 C. 15 D. 14

5. In the triangle below, angle $\hat{B}$ and $\hat{C}$ are $40°$and 60° respectively. Angle marked d is an exterior angle.



a. Fill in **CONJECTURE**: Angles in any triangle add to _______. (2)

A. $180°$
B. $90°$
C. $360°$
D. $30°$

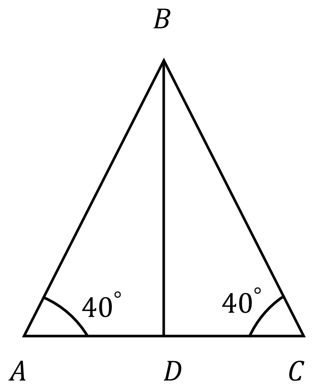
b. Fill in **CONJECTURE**: The exterior angle of a triangle is ______________ to the sum of the opposite interior angles. (2)

A. Equal
B. Add up to 90°
C. Not equal
D. Add up 180°

c. What is the size of angle marked d? (3)

A. $40°$
B. $60°$
C. $120°$
D. $100°$

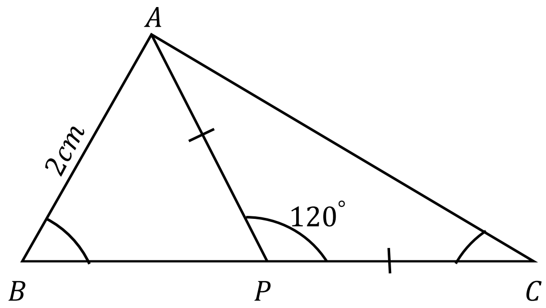
6. In the triangle ABC, BD bisects angle $A\hat{B}C$. What is the angle measure of $A\hat{B}D$? (1)



A. 80° B. 100° C. 60° D. 50°

PART 2:

7. Triangle ABC is right-angled at A, and triangle ABP is equilateral with $AB = 2cm$.



Calculate the sides PC and BC in that order. (3)

A. $2cm\ and\ 2cm$

B. $4cm\ and\ 2cm$

C. $4cm\ and\ 6cm$

D. $2cn\ and\ 4cn$

8. Consider each statement of triangles carefully, write **A** for YES or **B** for NO

a. Is it possible to have a right angled equilateral triangle? **A**. YES **B.** NO (1)

b. Is it possible to have an acute angled isosceles triangle? **A.**YES **B**. NO (1)

c. Is it possible to have a right angled scalene triangle? **A.** YES **B** .NO (1)

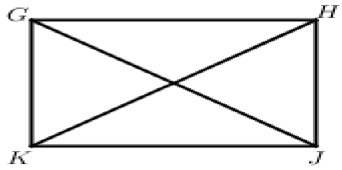
d. Is it possible to have a right angled isosceles triangle? **A.** YES **B**. NO (1)

e. Is it possible to have an obtuse angled isosceles triangle? **A.** YES **B.** NO (1)

SECTION B: Geometry of Quadrilaterals 20 marks

PART 1:

9. In a rectangle $GHJK, GJ$ and HK are the diagonals.



Which of the following is **NOT TRUE** in every rectangle? (1)

A. There are four right angles.

B. There are four sides.

C. The diagonals have the same length.

D. All sides have the same length.

10. A rhombus is a four sided figure with all sides of the same length.

Which of the following is **NOT TRUE** in every rhombus? (1)

A. The two diagonals have the same length.

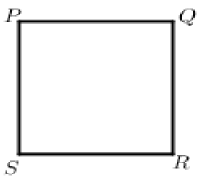
B. Each diagonal bisects two angles of the rhombus.

C. The two diagonals are perpendicular.

D. The opposite angles have the same measure.

11. $PQRS$ is a square.

Which relationship is **TRUE** for all squares? (1)



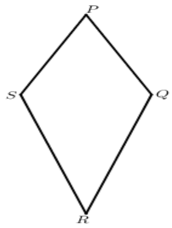
A. PR and RS have the same length.

B. QS and PR are perpendicular.

C. PS and QR are perpendicular.

D. PS and QS have the same lengths.

12. $PQRS$ is a kite.



Which of the following **NOT TRUE** in every kite? (1)

A. $PQRS$ have two pairs of sides of equal length.

B. PR and QS are perpendicular.

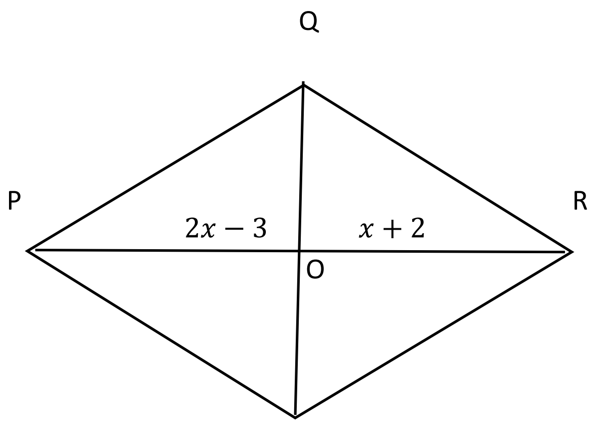
C. Angle P and R have the same measure.

D. Both diagonals bisect each other.

13. Which quadrilateral has all sides of equal measure but not necessarily, all angles of equal measure? (1)

A. Square B. Rhombus C. Rectangle D. None of the above

14. Diagram PQRS is a rhombus. The length of $PO = 2x - 3$ and $OR = x + 2$



ation $2x - 3 = x + 2$

(1)

A. All four sides of a rhombus are equal.

B. Diagonals of a rhombus bisect each other.

C. Opposite sides of a rhombus are parallel.

D. Diagonals of a rhombus are perpendicular.

15. Which statement is a good definition of a rectangle? (1)

A. A rectangle is a parallelogram with four equal sides.

B. A rectangle is a shape with two pairs of parallel and equal sides.

C. A rectangle is a shape with four sides.

D. A rectangle is quadrilateral with four equal angles.

PART 2:

16. The parallelogram below has $\widehat{A}$= 105°and $AD = 8cm$ and $DC = 16cm$.

a. Fill in the **CONJECTURES:**

(i) The opposite angles of a parallelogram____________ (1)

A. Are equal
B. Add up to 90°
C. Are not equal
D. Add up 180°

(ii) The consecutive angles of a parallelogram add up to ______° (1)

A. 90
B. 180
C. 360
D. 45

b. Find the lengths of AB and BC (2)

A. $AB = 8cm\ and\ BC = 16cm$
B. $AB = 8cm\ and\ BC = 8cm$
C. $AB = 16cm\ and\ BC = 8cm$
D. $AB = 16cm$ and $BC = 16cm$

c. Calculate angles $\widehat{B}$, $\hat{C}$ and $\widehat{D}$ (4)

A. $\widehat{B} = 75$, $\hat{C} = 105$ and $\widehat{D} = 75$
B. $\widehat{B} = 105$, $\hat{C}$=105 and $\widehat{D} = 105$
C. $\widehat{B} = 75$, $\hat{C} = 75$ and $\widehat{D} = 105$
D. $\widehat{B} = 75$, $\hat{C} = 105$ and $\widehat{D}$=105

17. Match the statements in column A and the quadrilaterals in column B.

Write the letter only next to the number. (5)

	COLUNM A	COLUMN B
a.	A quadrilateral with four equal sides and four right angles.	A. Parallelogram
b.	It has four right angles and its diagonals which are equal in length and bisect each other, but not perpendicularly then the quadrilateral is-------------	B. Rectangle
c.	If the quadrilateral has all sides equal, diagonals different in length and bisect each other perpendicularly, it is--------	C. Square
d.	If only one diagonal bisects the other diagonal perpendicularly, then the quadrilateral is ----------------	D. Rhombus
e.	The angles are not right angles, not all sides are equal and both its diagonals bisect each other-------------	E. Kite

TOTAL MARKS-40

Thank you for your participation!

MARKING GUIDE

Section A: Geometry of Triangles

PART 1:

NO.	ANSWER	MARKS
1.	A	1
2.	C	1
3.	B	1
4.	B	1
5a.	A	2
b.	A	2
c.	C	3
6.	D	1

PART 2

NO.	ANSWER	MARKS
7.	D	3
8a.	B	1
b.	A	1
c.	A	1
d.	A	1
e.	A	1

[20 Marks]

Section B: Geometry of Quadrilaterals

PART 1:

NO.	ANSWER	MARKS
9.	D	1
10.	A	1
11.	B	1
12.	C	1
13.	B	1
14.	B	1
15.	D	1

PART 2:

NO.	ANSWER	MARKS
16 a (i).	A	1
(ii).	B	1
b.	C	2
c.	A	4
17 a.	C	1
b.	B	1
c.	D	1
d.	E	1
e .	A	1

[20 Marks]

TOTAL =40 MARKS

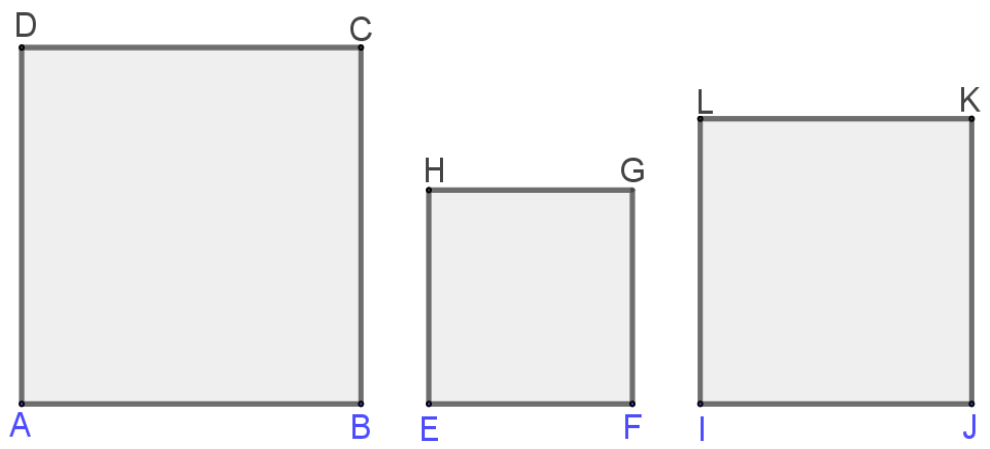
APPENDIX D: A SAMPLE OF A LESSON BASED ON PROPERTIES OF SQUARES WITH ACTIVITIES

Investigating the properties of a square

- **Activity 1: <u>sides of a square</u>**

i. Measure all the lengths of the four sides of the squares and record in the table below:

❖ Given the three SQUARES



Square					
ABCD		**EFGH**		**IJKL**	
Side	cm	Side	cm	Side	cm
AB		*EF*		*IJ*	
DC		*HG*		*LK*	
AD		*EH*		*IL*	
BC		*FG*		*LK*	

ii. Write what you notice about the lengths of the sides of a square____

iii. Fill in the **CONJECTURE**:

The lengths of the sides of a square are_____________

❑ **Activity 2: <u>angles of a square</u>**

i. Measure the sizes of all the four angles in each square and record in the table below:

Square					
ABCD		**EFGH**		**IJKL**	
$\hat{A}$		$\hat{E}$		$\hat{I}$	
$\hat{B}$		$\hat{F}$		$\hat{J}$	
$\hat{C}$		$\hat{G}$		$\hat{K}$	
$\hat{D}$		$\hat{H}$		$\hat{L}$	
Sum of the interior angles					

ii. Write what you notice about the sizes of the angles of a square:

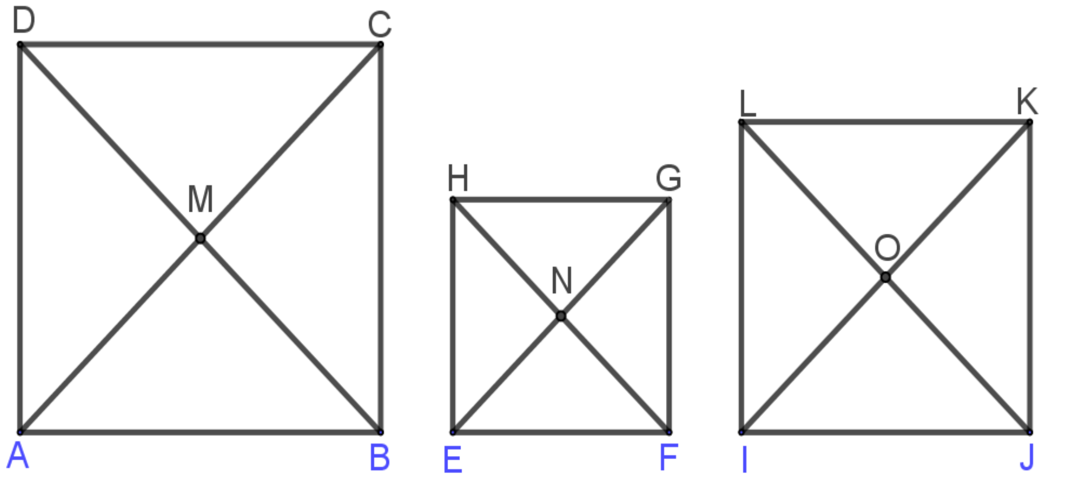
____

iii. Fill in the **CONJECTURES**:

(a) **The sizes of the angles of a square are______ and of _____^{o} each.**

(b) **The sum of the interior angles of a square is_______^{o}**

❖ **Given are the three SQUARES with diagonals drawn:**



Square					
ABCD		**EFGH**		**IJKL**	
Length	cm	Length	cm	Length	cm
AC		*EG*		*IK*	
BD		*FH*		*JL*	

ii. What do you notice about the lengths of the diagonals of the square?

____

iii. Fill in the **CONJECTURE**:

The lengths of the diagonals of a square are ____________

iv. Measure the lengths of the line segments from each of the vertex to the point of intersection of the diagonals of each square and record on the table below:

Square					
ABCD		**EFGH**		**IJKL**	
Length	cm	Length	cm	Length	cm
AM		*EN*		*IO*	
MC		*NG*		*OK*	
BM		*FN*		*JO*	
MD		*NH*		*OL*	

v. What do you notice about the lengths of the line segments from the vertex to the point of intersection of the diagonals in each square? __________

vi. Fill in the **CONJECTURE**:

At the point of intersection, the diagonals of the square

are __________ each other.

vii. Measure the size of the angle where the diagonals intersect for all three squares.

(a) Square ABCD: __________^{o}

(b) Square EFGH: __________ °

(c) Square IJKL: __________ °

viii. Fill in the **CONJECTURE**:

At the point of intersection, the diagonals of a square are________

ix. Measure the sizes of the two angles formed by the diagonals at each vertex and complete the table below.

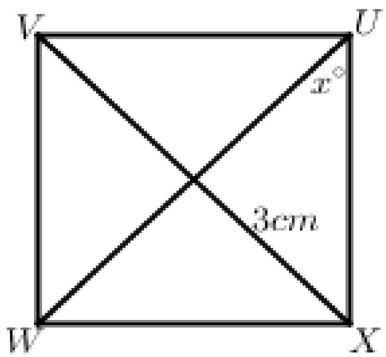
Square	**ABCD**				**EFGH**				**IJKL**			
Vertex	***A***	***B***	***C***	***D***	***E***	***F***	***G***	***H***	***I***	***J***	***K***	***L***
$\measuredangle_1$												
$\measuredangle_2$												

x. Write what you notice about the sizes of the two angles at each vertex. _______________

xi. Fill in the **CONJECTURE:**

The diagonals of a square _________ the angles at the vertices.

- **Classwork/Homework**
  (a) Find the values of the diagonals VX and UW.
  (b) Find the value of x°.



End of Lesson