CONSTRUCTIVIST ASSISTIVE TECHNOLOGY IN A MATHEMATICS CLASSROOM FOR THE DEAF: AN EXPERIMENT IN A RURAL NAMIBIAN PRIMARY SCHOOL

by

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Declaration

I declare that “Constructivist Assistive Technology In A Mathematics Classroom For The Deaf: An Experiment In A Rural Namibian Primary School” is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

I further declare that I submitted the thesis/dissertation to originality checking software and that it falls within the accepted requirements for originality.

I further declare that I have not previously submitted this work, or part of it, for examination at Unisa for another qualification or at any other higher education institution

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Abstract (150 word limit at Unisa)

The study investigated assistive technology for the deaf, specifically applied to the teaching and learning of mathematics at a rural Namibian special primary school. The problem was the lack of prior research about the effects of Constructivist assistive technology for guiding Namibian special schools and educators. The objective was to conduct an experiment with deaf learners and interviews with the teachers involved. The study was a mixed methods study, involving quantitative academic achievement data and qualitative interview data. The findings suggest that there was a statistically significant effect on the multiplication and division achievement of the learners, but not their addition and subtraction achievement. The emergent Constructivist-related categories were collaborating, cooperating, exploring, self-assessing, learning from errors, seeking knowledge independently, self-regulating, self-reflecting, metacognitive thinking and being self-aware. These scientific insights contribute to the field and stem from a useful method for reviewing and selecting an appropriate learning theory and assistive technology.

Isifundo socwaningo siphenya ngobuchwepheshe obuluncedo kulabo abayizimpumputhe, ikakhulukazi lolu ewaninga lumayelana nokufundisa kanye nokufundwa kwesifundo sezibalo esikoleni sabakhubazekile endaweni yasemakhaya ngaseNamibia. Inkinga lapha ukusweleka kocwaningo lwangaphambili olumayelana nemithintela yohlelo lobuchwepheshe oluncedayo losolwazi abangama-constructivists ngokuhola izikole zabakhubazekile zaseNamibia kanye nabafundisi. Inhloso kwaye kuwukwenza ucwaningo oluphathekayo kanye nabafundi abakhubazeke amehlo kanye nenhlolovo nothisha ababandakanyekayo, ngokusebenzisa ucwaningo oluxubile, oluxuba idatha mayelana nempumelelo kwezemfundo kanye nedatha yezamanani yenhlolovo. Okutholwe wucwaningo kuchaza ukuthi kunomthelela obonakalayo wezamanani mayelana nempumelelo yeKhono lokuphindaphinda kanye nokwehlukanisa, kodwa hayi impumelelo yabo ngokwekhono lokuhlanganisa kanye nokunciphisa. Izigaba ezihambisana nosolwazi abakhasayo zisebenza ngokuncedana, ngokusebenzisa, ngokuvumbulula, ngokuzihlola wena siqu sakho, ngokufunda ngokwenza amaphutha, ngokucinga ulwazi ngokuzimela, ngokuzenzela imigomo, ngokubheka impumelelo yakho, ngokucabangisisa ngokusebenzisa ulwazi kanye nokuzibhekisisa. Lolu lwazi lwezesayensi lunomthelela emkhakheni kanti lususelwa endleleni esebenzayo
ngokubuyekeza kanye nokukhetha ithiyori yokufunda efanele kanye nohlelo oluncedayo lobuchwepheshe.

Die studie het ’n ondersoek na bystandstegnologie vir dowes, spesifiek ten opsigte van hoe dit in die onderrig en leer van wiskunde by ’n landelike spesiale laerskool in Namibië toegespas word, behels. Die navorsingsprobleem was die gebrek aan navorsing oor die effek van konstruktivistiese bystandstegnologie wat leiding aan Namibiese spesiale skole en opvoeders kan bied. Die navorsingsdoelwit was om ’n eksperiment met dowe leerders uit te voer en onderhoude met die betrokke onderwysers te voer as deel van ’n gemengdemetodestudie, wat die insameling van kwantitatiewe data oor akademiese prestasie en kwalitatiewe onderhoudata behels het. Die bevindings van die studie dui op ’n statisties beduidende effek op die leerders se prestasie met betrekking tot vermenigvuldiging en deling, maar nie hulle prestasie met betrekking tot optel en aftrek nie. Die voortkomende konstruktivisties-verwante kategorieë is meewerking, samewerking, verkenning, selfassessering, die vermoë om uit foute te leer, ’n onafhanklike soeke na kennis, selfregulering, selfbesinning, metakognitiewe denke en selfbewussyn. Hierdie wetenskaplike insigte lewer ’n bydrae tot die studieveld en spruit uit ’n nuttige metode vir die beoordeling en seleksie van geskikte leerteorieë en bystandstegnologie.

**Keywords** (in alphabetical order):

Assistive technology, Constructivism, deaf learners, field experiment, interviews, mathematics achievement, Namibia, primary education, special education, teaching and learning
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List of Academic Outputs Based on this Research


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Glossary of Key Terms

- **Assistive technologies**: Assistive technologies refer to “products, resources, methods, strategies, practices, and services to enhance the functional capability related with the activity and participation of people with deficiencies, disabilities, or reduced mobility to improve their autonomy, independence, quality of life, and social inclusion” (Cavanaugh, 2002, p. 1).

- **Deaf**: The term deaf refers to people “who have predominantly profound or severe hearing losses without the use of hearing aids” (Lang, 2002, p. 1).

- **Disability**: The term disability refers to “a limitation or restriction of ability to participate in an activity within the range considered normal for person due to mental or physical condition” (Oliver, 1996, p. 2). Disability has various characteristics such as blindness, mobility impairments, and deafness, to mention a few (Reverte, 2009).

- **Learning**: Learning is “the process of discovery that generates new understanding about ourselves and the world we live in” (Ranson, Martin, Nixon, & McKeown, 1996, p. 5).

- **Special school**: Includes “schools that serve only students with disabilities. These include schools for the deaf, as well as others (e.g., schools for the blind and those serving students with multiple disabilities)” (Shaver, Marschark, Newman, & Marder, 2014, p. 5).

- **Teaching**: Teaching is defined as an “interactive process, primarily involving classroom talk, which takes place between teacher and pupil and occurs during certain definable activities” (Bhowmik, Banerjee, & Banerjee, 2013, p. 1).
Chapter 1: Introduction to the Research

1.1 Introduction
This study investigated assistive technology for the deaf, specifically applied to the teaching and learning of mathematics at a rural Namibian special primary school. The goal of Chapter One is to provide a foundation for the study. This goal is fulfilled through the achievement of the following chapter objectives, putting the study in context, exposing the research problem, research objectives and research questions, explaining the significance of the study, providing a summary of the research design and presenting the study’s limitations.

1.2 Background and context
Generally, people with disabilities face many challenges (Indongo & Mufune, 2015) especially those related to the issues of social identity and education (Groce, 2004). In educational environments, children with disabilities should have the same opportunities as non-disabled children (Brodin, 2010) so that they can, in adulthood, support themselves and contribute to society.

This study focused on children with hearing disabilities, which is a significant disability since deafness or partial deafness is acknowledged to affect approximately five percent of the global population, and in 2018, this was about four hundred and sixty million people with thirty four million of these being children (WHO, 2018a). Of these children, almost nine million are in Sub-Saharan Africa, which includes the country of Namibia (WHO, 2018b).

Deaf learners face particular challenges, which may include growing up in a family that is not competent in sign language (Anglin-Jaffe, 2013; Luckner, Bruce, & Ferrell, 2016; Slobin & Hoiting, 2002). Sign language is a common system of communication for deaf people and is based on visual signs and gestures. In addition, having to learn from textual teaching materials can be difficult, especially in relation to sign language (Verlinden, Zwitserlood, & Froweин, 2005). Such challenges can actually result in cognitive deficits that negatively impact academic achievement (Humphries et al., 2016; Luckner et al., 2016) and it has been reported, based on data analysed over the last three decades, that deaf and hard-of-hearing students generally lag behind their hearing peers in academic achievement (Johnson, 1989; Qi & Mitchell, 2011).

A prominent and promising approach to addressing deaf learners’ academic achievement and the many other challenges experienced by people with disabilities is assistive technology.
Chapter 1: Introduction to the Research

Assistive technologies have been widely used by service providers such as educators and often in special education (Boone & Higgins, 2007). Some instances of assistive technology have been shown to enhance and improve the functional capabilities of students with various disabilities (Rose, Hasselbring, Stahl, & Zabala, 2005) and provide them with opportunities to be independent, gain relevant experience and have prospects similar to learners that are not disabled (Holder-Brown & Parette Jr, 1992; Wong & Cohen, 2011). With reference to deaf learners, for example, one study reported that using animated sign language through the presentation of a video of a person or via an avatar on a computer provided more lifelike signalling and sped up the teaching process (Verlinden et al., 2005). It has also been stressed that assistive technology should be used as early as possible to improve learning (Holder-Brown & Parette, 1992).

However, assistive technology alone is not a panacea for teaching learners that have disabilities, since there are many reports of ineffective assistive technology usage (Adamo-Villani & Wilbur, 2008; Bouck et al., 2006; Bouck & Weng, 2014; Hayden, Astrauskas, Yan, Zhou, & Black Jr, 2011; Hetzroni & Shrieber, 2004; Söderström, 2012). Instead, it has been indicated that assistive technology should be implemented in conjunction with a complementary learning theory for improved chances of success (Abbas, Lai-Mei, & Ismail, 2013; Duhaney & Duhaney, 2000; Kelly, 2012). After analysing the literature on applicable learning theories in Section 2.5.4.1, the study proceeded with Constructivism as the appropriate complementary learning theory for implementing the study’s assistive technology. The study refers to the implementation of its learning theory and assistive technology together as Constructivist assistive technology.

In addition, learning, especially with young learners, does not happen without some form of involvement by teachers. Teachers are instrumental in the learning process and perform the essential teaching that is intrinsic to teaching and learning, both with non-disabled learners and disabled learners (Easterbrooks, Stephenson, & Mertens, 2006). Thus, teachers are viewed as an indispensable part of learning with assistive technology and imperative in the implementation of any complementary teaching approach (Mohamed, 2018; Naraian & Surabian, 2014).

Within the aforementioned context, the study focused on mathematics education as mathematics is a life skill that is needed everywhere in the world and deaf learners need mathematics just as much as other learners (Akpan & Beard, 2014; Drouhard 2015). Over the years, many efforts have been made to improve mathematics education generally (Lortie-Forgues, Tian, & Siegler, 2015). Mathematics is regarded as a way to develop abstraction and
reasoning skills and to acquire the language of science and technology. Furthermore, young deaf children should also acquire mathematical skills such as the ability to count, label, and compare columns on graphs, as early as possible starting from the Kindergarten stage (Kritzer, 2009).

1.3 Research problem, objective and questions

The researcher is a citizen of Namibia and, therefore, focused the study in the Namibian context. Furthermore, Namibia is committed to providing equal educational opportunities to disabled learners under the United Nations (UN) Convention on the Rights of the Child (1989) (OHCHR, 1989), which includes providing support and even assistive devices to those with disabilities (Namibia Ministry of Education, 2013; Office of the Prime Minister of Namibia, 2004). It has also been stated that disabled people have the right to affordable assistive technologies and the provision of such assistive technologies is a national and international responsibility (Borg, Larsson, & Östergren, 2011).

However, according to the researcher’s general knowledge of the schools for the deaf in Namibia, there appears to be no assistive technology usage by deaf learners in primary or secondary schools throughout Namibia. Table 1 presents all the schools for deaf learners throughout Namibia (CLaSH, 2016) as at 2016 and illustrates the lack of assistive technology usage by deaf learners. This is the real-world problem identified by the study. Essentially, given the aforementioned potential benefits of assistive technology and the learning challenges that are often experienced by deaf learners, the absence of assistive technology potentially disadvantages these deaf learners.

**Table 1:** Primary and secondary schools for deaf learners for all regions in Namibia

<table>
<thead>
<tr>
<th>Region</th>
<th>Deaf Unit/School</th>
<th>Assistive Technology Used?</th>
<th>Grades for Deaf Learners</th>
<th>Subjects Taught to Deaf Learners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Khomas Region</td>
<td>National Institute for Special Education (NISE) Windhoek School for the Deaf</td>
<td>No</td>
<td>8-10</td>
<td>Languages, mathematics, natural science, life skills</td>
</tr>
<tr>
<td>Kavango East Region</td>
<td>Deaf Unit, Katima Combined School</td>
<td>No</td>
<td>1-10</td>
<td>Languages, mathematics, natural science, life skills</td>
</tr>
<tr>
<td>Kavango West Region</td>
<td>Deaf Unit, Andreas Haingura Kandjimi Primary School</td>
<td>No</td>
<td>1-7</td>
<td>Languages, mathematics, natural science, life skills</td>
</tr>
<tr>
<td>Ohangwena Region</td>
<td>Usko Nghaamwa Special School</td>
<td>No</td>
<td>0-6</td>
<td>Languages, mathematics, natural science, life skills</td>
</tr>
</tbody>
</table>
Following the identified real-world problem, the literature was searched to determine the extent to which the identified real-world problem has been addressed in the Namibian context. Searches were done on Google Scholar using the keywords such as “assistive technology+education+deaf+Namibia” and their combinations and derivatives, but no directly relevant research was returned about assistive technology in education specifically for the deaf in Namibia. Thus, there is no scientific evidence about the effects of assistive technology in education specifically for the deaf in Namibia for informing Namibian teaching and providing guidance to the Namibian schools and educators.

Nevertheless, from the searches, many related studies were returned that had been conducted in the developed world, as reviewed in Section 2.5.3. However, the Namibian context has substantial and distinctive contextual characteristics (Namibia Ministry of Education, 2013). These include resource scarcity, cultural and language differences and varying technology competencies relating to teaching and learning. Therefore, the study’s research problem is the lack of prior research about the effects of Constructivist assistive technology in education, specifically for the deaf in Namibia, for informing Namibian teaching and providing guidance to the Namibian schools and educators. Thus, the study makes an original contribution to the academic body of knowledge.

Consequently, the overall research objective was to provide scientific evidence, by conducting an experiment with assistive technology, with regards to the effects of Constructivist assistive technology for the deaf, specifically as applied to the teaching and learning of mathematics at a rural Namibian special primary school. This was achieved through the following sub-objectives:

1. Determining the appropriate learning theory and software.
2. Conducting an experiment with deaf learners and the Constructivist assistive technology and interviews with their teachers to understand how their teaching and their students’ learning was affected by the Constructivist assistive technology.

The rural Namibian special primary school was selected due to its accessibility and its contextual characteristics, which place its deaf learners at high risk of low academic
Chapter 1: Introduction to the Research

achievement (Namibia Ministry of Education, 2013). Accordingly, the study’s research questions were:
1. What learning theory was appropriate to guide learning environments mediated by technology?
2. What available software was appropriate for studying the effects of assistive technology and was suitable for the selected learning theory?
3. What was the effect of the Constructivist assistive technology on the mathematics achievement of the learners?
4. According to the teachers, who are regarded as experts in the selected teaching context, how was their teaching affected by the Constructivist assistive technology?
5. According to the teachers, who are regarded as experts in the selected teaching context, how were their students’ learning affected by the Constructivist assistive technology?
6. Based on the study’s results, what was learnt that could be of use to other researchers in the domain?
7. Based on the study’s results, what recommendations can be made for School management, teachers and Namibian policy?

1.4 Research design summary
In order to answer Research Question One, the literature was analysed and synthesized in Section 2.5.4.1. To answer Research Question Two, the literature and internet were searched and analysed for available software that was also suitable for the selected learning theory and then evaluated based on relevant decision criteria, and this is presented in Section 2.5.4.2. To answer Research Questions Three to Seven, the study conducted an experiment with learners and interviews with the teachers involved with the experiment. Thus, the study was appropriately a mixed methods study, involving quantitative academic achievement data and qualitative interview data.

1.5 Scope and limitations
The study’s scope is deaf children in grade three and the subject of mathematics in a mostly rural region in Namibia, at a special school. Grade three is a grade where the children learn to build and understand foundational and basic mathematical concepts such as counting, which they require for subsequent mathematics concepts (Rudasill, Gallagher, & White, 2010) and they were at an age where it was easier for them to understand instructions and communication relating to the purposes of the study. While this scope limited generalisability
and transferability to all types of disabilities, all primary grades and all African countries, it allowed for an in-depth study of the effects of the Constructivist assistive technology in a very resource constrained or stressed environment, with valuable insights for broader and more generalised studies.

1.6 Layout and dissertation
Chapter One introduced the research and clarified the research problem, objectives and research questions. Chapter Two presents the literature review and provides answers to Research Questions One and Two and achieves Sub-objective One. Chapter Three explains and justifies the research design in relation to the research problem and Chapter Four is the presentation, analysis and interpretation of the data and provides answers to Research Questions Three to Five achieves Sub-objective Two. Chapter Five presents the research conclusions based on the research findings and provides answers to Research questions Six and Seven.

1.7 Chapter summary and conclusions
Chapter One introduced the study and presented the study’s background and context, which is Constructivist assistive technology for deaf learners, specifically applied to the teaching and learning of mathematics at a rural Namibian special primary school. The chapter’s objectives have been achieved by the provision of the study’s context, the research problem, research objectives, research questions, the study’s significance, the research design summary and the study’s limitations. Thus, the goal of the chapter has been accomplished, which was to provide a foundation for the research.

The chapter explained that it is potentially beneficial for disabled learners to use Constructivist assistive technology and that it should be used as early as possible. The chapter also demonstrated that assistive technology was not apparent for deaf learners in primary and secondary schools throughout Namibia. In addition, the importance of developing mathematical skills and learning mathematics was substantiated. This presented an important research problem, which is to make known the effects of Constructivist assistive technology for the deaf, specifically applied to the teaching and learning of mathematics at a rural Namibian special primary school.

The chapter has value for educators of deaf learners throughout Namibia as it highlighted the necessity for research relating to the use of Constructivist assistive technology for the deaf, specifically applied to the teaching and learning of mathematics. In addition, this chapter
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presented research questions whose answers may add to the knowledge base for teaching and learning in these contexts. The next chapter is the literature review, which aims to provide a conceptual review and discussion of the research domain.
Chapter 2: Literature Review

2.1 Introduction
Chapter One provided a foundation for the research, and presented the study’s research problem, objectives and research questions. Chapter Two follows with a review of relevant literature. Chapter Two scrutinises previous studies and provides a conceptual overview of the research domain. In addition, Chapter Two discusses the salient aspects of relevant research and substantiates the study.

The main goal of the chapter is to synthesise previous studies relating to the research problem. This goal is fulfilled by achieving the following chapter objectives, explaining the literature review process to demonstrate a rigorous literature review, uncovering key theories, models, frameworks and phenomena in the domain, clarifying the contribution of the research, answering Research Questions One and Two and achieving Sub-objective One.

The chapter proceeds by detailing the literature review process, the literature search process and the literature analysis and synthesis process, which involves the development of a literature matrix. Subsequently, the relevant themes synthesised from the literature, aided by the literature matrix, are discussed. These themes are general teaching challenges with disabled learners, mathematics teaching and learning relating to disabled and deaf learners, assistive technology and learning theories. Lastly, the chapter’s summary and conclusions are presented.

2.2 Literature review process
The review process was conducted in a systematic manner following an input-processing-output approach (Levy & Ellis, 2006). The approach involved collecting academic articles for the review, preparing and organising those articles into categorised themes and classifications and, lastly, writing and reporting the review (Bandara, Miskon, & Fielt, 2011). Systematic searches facilitated the accumulation of relevant literature (Levy & Ellis, 2006). The research articles that were included were only those that made a meaningful contribution to the research problem (Randolph, 2009).

2.3 Literature search process
A comprehensive search of previous studies began with searches in scholarly literature databases in order to gather relevant research. The process of searching for academic articles and journals continued with different search tools such as library catalogues, search engines
and on-line databases using a number of different keywords and keyword combinations (Rowley & Slack, 2004).

In addition, the literature search process involved keyword searches on the Open Public Access Catalogue (OPAC) of the University of Namibia (UNAM) library and the University of South Africa’s (UNISA) electronic databases, subject gateways and search engines. The identification of keywords comprised selecting nouns and adjectives that referred to the problem statement (Ridley, 2012).

Furthermore, backward and forward searches improved the validity of the review (Bansal, 2005). In backward searching, the citations within relevant articles were used to discover previously written and relevant research. In forward searching, tools like Google Scholar and Web of Science, being the electronic version of the Social Sciences Citation Index, were used to identify articles that cited the relevant articles already identified.

2.4 Literature matrix

The literature matrix is a conceptual framework presented in a table format consisting of rows and columns (Scherpereel, Van Koppen, & Heering, 2001). The literature matrix enabled the researcher to analyse and synthesise conceptual relationships that exist in the research domain. The literature matrix presented research articles per concept, which enabled the researcher to develop relevant concepts and themes (Klopper & Lubbe, 2011) in relation to the problem statement. Critical comparative analysis was then possible (Klopper & Lubbe, 2011). The literature matrix was developed to achieve the goal of the chapter. The literature matrix is provided in Appendix A and each of the themes presented in the literature matrix are discussed in the next section.

2.5 Literature review themes

2.5.1 General teaching challenges with disabled learners

Teachers play a central role in education, and special education is no different. However, special education poses major challenges to teaching practices and even the administrative practices of schools (Jerlinder, Danermark, & Gill, 2010). For example, a study conducted in Sweden to investigate the attitudes of teachers towards learners with physical disabilities concluded that while the teachers were positive about teaching learners with special needs, access to training, school support and teaching skills were challenges (Jerlinder et al., 2010).

Similarly, in a Turkish study, one hundred and ninety-four general education teachers were asked for their opinions about teaching learners with special needs (Rakap & Kaczmarek,
2010). The teachers indicated that they were willing to teach learners with special needs provided they could attend life skill courses, training and workshops and be provided with materials and essential support in classrooms.

In Africa, in a report on special education in Zimbabwe, it was indicated that teachers usually find it difficult to give class lessons to learners with special needs because of the lack of expertise in teaching disabled children who may have many different types of disabilities (Deluca, Tramontano, & Kett, 2014). The report also indicated that twenty percent of the teachers in mainstream schools in Zimbabwe were not aware of how to teach learners with different types of disabilities and they did not have any experience teaching in special schools. Other challenges included the lack of resources such as assistive devices.

Chireshe (2013) acknowledges that challenges facing special education include the lack of trained teachers, the lack of specific policies on special education and the lack of assistive devices for learners with special needs. In addition, teachers lack confidence to guide and teach learners with special needs unless they undergo in-service training and capacity building (Kisanji, 1999).

In a study conducted in Namibia at the Gabriel Taapopi Secondary School, it was found that teachers faced many challenges when teaching learners with special needs (Josua, 2013). These included the physical make-up of the school environment, overcrowded inclusive classrooms, lack of training for staff, lack of teaching and learning facilities and materials, restriction of learners with visual impairments from certain subjects in the curriculum, social exclusion and the lack of targeted measures to include learners with visual impairments in social and other academic programmes at the school.

A case study conducted in Botswana found that most teachers preferred teaching learners with mild disabilities only, because they lacked experience teaching children with severe disabilities (Mukhopadhyay, Nenty, & Abosi, 2012). Additional challenges according to the study included resource constraints, funding for special schools (Peters, 2003) and also the fact that learners with special needs require higher participation in classroom environments, greater collaboration and peer assistance (Lang, Stinson, Kavanagh, & Basile, 1999).

Research has also been done to measure assistive technology proficiency in teachers of students with visual impairments. It was found that the teachers’ low proficiency stunted their students’ skills development and consequently resulted in poorer post-secondary education and employment outcomes (Siu & Morash, 2014).

Specifically, Namibia faces challenges teaching disabled learners due to the lack of teaching knowledge, the lack of teaching aids such as equipment to assist the learners and the lack of
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general resources (New Era Newspaper, 2015). In addition, there are not enough schools in Namibia for special learners (Uukongo, 2014). This exacerbates the challenges for Namibian teachers and necessitates an appropriate policy for special education that would identify the necessary training for teachers.

Although the teaching challenges are many and varied, major challenges appear to be the lack of training and resources, such as assistive technologies. Thus, special education requires skilled teachers to teach learners with special needs and the usage of resources such as assistive technologies, which offer the potential aid to help both teachers and learners in these classroom environments.

2.5.2 Mathematics teaching and learning relating to disabled and deaf learners

Many studies have been conducted exposing the challenges encountered by children with special needs when learning mathematics. As an illustration, a study was conducted on deaf learners from grade six to twelve to assess their mathematics word problem solving skills (Kelly, Lang, & Pagliaro, 2003) and it was found that the learners struggled due to language difficulties. A key challenge faced by deaf learners is insufficient English language reading ability, which is needed to understand mathematical activities in the classroom (Naidoo, 2009).

Another study aimed to identify the different ways in which deaf and hearing learners respond to mathematical questions (Swanwick, Oddy, & Roper, 2005). The areas of concern were grouped into language issues, pupils’ networking methods, written responses in English and difficult to teach items. The authors found that the language of mathematics was difficult for deaf learners, the English language was a burden for the deaf learners and, as a result, deaf learners were less successful than hearing learners.

It has also been reported that deaf and hard of hearing students experienced a delay in solving mathematical problems when compared to hearing students because of language acquisition (Power, Zevenbergen, & Hyde, 2003). In contrast, Ray (2001) found that the challenges faced by deaf learners when solving mathematical word problems did not involve language acquisition challenges, but learners needed more mathematical word solving activities.

The literature provides more evidence that deaf learners find it difficult to understand teacher presentations on mathematics (Zarfaty, Nunes, & Bryant, 2004). Moreover, deaf learners have been found to be less exposed to mathematical activities than hearing learners, who hear about mathematical concepts from birth and are involved in mathematics at an early age (Swanwick et al., 2005). Thus, deaf learners may not have developed an understanding of
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mathematical concepts and foundations in their early childhood years, which limits their mathematical development (Kritzer, 2009).

In a study about mental mathematical representation skills for children with special needs, a conceptual model was developed for solving mathematical problems for these learners (Desoete, Roeyers, & De Clercq, 2004) and they established that mathematical learning at a young age defines students’ representation skills for solving mathematical problems when they reach higher grades. This is consistent with the findings of Lee (2010), which indicated that deaf students did not have enough representation skills and opportunities to solve mathematical problems in classroom environments. Lee (2010) also found that the learning challenges faced by deaf learners included a lack of knowledge and language structure for understanding mathematical concepts.

A proposed solution was a concrete representational abstract (CRA) framework of instruction that helped learners with special needs in mathematics (Agrawal & Morin, 2016). The CRA framework was a process where a teacher guided a student through a mathematical concept and its corresponding computational processes by using manipulatives and visual representations that illustrated the concepts along with the numbers. Similarly, the CRA framework was used together with a strategic instruction model (SIM), which is an evidence-based supplemental mathematical program model, to address instructional practices in mathematics for learners with special needs to improve their understanding of numbers and operations (Flores, Hinton, Strozier, & Terry, 2014).

It has also been demonstrated that mathematical learning for deaf learners was not dependent on number presentation skills but rather on spatial presentation (Zarfaty et al., 2004), where deaf learners were good at representing numbers that were presented in spatial arrays, as the learners understood more easily and quickly when the teacher presented numbers spatially.

Furthermore, teaching approaches have been found to be one of the most important factors for students gaining knowledge and learning how to transfer knowledge into their own contexts (Ünal & İnan, 2010). In a national survey in the United States of America (USA) about the level of knowledge of mathematics teachers who use technology to teach deaf learners (Pagliaro, 1998), the author recommended that teachers familiarise themselves with mathematics instructional technology, work together for the continuous improvement of their mathematics programs, ensure technology is available and used as a tool to enhance learners’ understanding and knowledge and instruction and mathematics education should be made a priority for deaf learners.
In addition, deaf learners and learners with hearing impairments require sign language observers who are able to help them interpret their teachers’ verbal and written communications (Mousley & Kelly, 1998). They state that deaf learners can only effectively learn mathematics when they are taught with sign language observers, who can clarify activities using sign language. Furthermore, they concluded that deaf learners need to be given step-by-step instructions, interactive activities and be allowed to conceptualise in their own way.

Interestingly, a study involving an origami mathematics lesson for learners who were deaf or had hearing impairments (Chen, 2006) created active participation instead of pupils being passive recipients of knowledge. The study indicated that it was vital to include visuals for deaf and hearing-impaired learners, including visual games and activities (Chen, 2006). Similarly, Cakmak (2009) conducted a study on origami for education and concluded that when origami was integrated with mathematics activities students were better able to develop mathematical skills and learn and use mathematical concepts. Origami is a Japanese system of folding paper into shapes, which represent objects.

It is repeated that teachers should use technology such as visualised and captioned materials and the Internet, to teach learners with special needs (Easterbrooks et al., 2006). Technology can be a useful tool to teach learners who are deaf as it improves their comprehension and knowledge in comparison to traditional classroom environments. In support, Shepherd and Alpert (2015) conducted a study demonstrating technology as an instructional tool for deaf learners. The study found that learners with special needs became more interested, their understanding improved and they became more actively involved in classroom activities.

The aforementioned literature provides evidence that there are many challenges for disabled learners as they attempt to learn mathematics. The literature also provides evidence that assistive technology has the potential to improve the learning of these learners. The following sub-section further explores the research relating to assistive technology for disabled learners.

2.5.3 Assistive Technology

The literature exposes both the potential for assistive technology to improve the education of disabled learners and the many challenges experienced with the use of assistive technologies (Bouck et al., 2006). This sub-section begins by presenting those studies where assistive technology improved the education of disabled learners. Thereafter, those studies where assistive technology was not effective in improving the education of disabled learners are provided. Subsequently, the studies that showed mixed results are presented.
In a study involving people with severe motor impairments, a brain computer interface (BCI) module that translated commands from users that could not use conventional aids was used (Cincotti et al., 2008). The system was designed to improve their mobility and showed positive results. Another study that involved primary and secondary school learners with hearing difficulties and disabilities, and an interactive whiteboard (IWB) also showed success (Mead, 2012). The IWB allowed students to write, make notes and identify different aspects in their school activities. In addition, photos and videos were also displayed on the IWB. It was confirmed that IWBs are effective tools for student engagement and motivation.

Another case study was done that focussed on improving literacy with assistive technology in classrooms for learners with disabilities (Beck, 2002). The assistive technology included picture communication symbols, adapted books, computers with intellikeys and an overlay maker. Although learners took time to adapt to the assistive technology before using it, it was reported as successful. In a study focussing on students with reading and writing disabilities, an application called Prizmo was used (Fälth & Svensson, 2015). The device was a multifunction application with an optical character recognition (OCR) reader and built-in speech synthesis. While Prizmo was never developed for schools, it could scan texts and synthesise speech for students who had reading problems. The Prizmo was found to improve the reading and writing of learners as well as their motivation. Another advantage of the application was that it was user friendly to both the learners and teachers.

Another learning tool for disabled learners consisted of an application framework called “talking paper” (Garzotto & Bordogna, 2010). The software enabled paper-based objects like cards, drawings and pictures to be converted into multimedia sources such as videos, sounds and animations for improved communication and learning by disabled learners. The study showed some improvement in the linguistic skills of the learners.

Also, a study that involved people with hearing loss used a multi-sensory learning (MSL) tool (Pan-ngum, Soonrach, Seesutas, Noymai, & Israsena, 2013). It was presented as a collection of games and modules to enhance the learning and memory skills of the learners. It consisted of three-dimensional (3D) animations of a girl that signed the chosen alphabet characters and other sensory objects. The authors concluded that the MSL tool was viable for enhancing the learning and memory skills of the learners.

Additionally, an assistive technology for the hearing impaired was introduced in Thailand as a language-teaching tool (Tumtavitikul et al., 2013). The e-Learning/m-Learning assistive technology enabled deaf learners to communicate in Thai with other learners who were not deaf. The assistive technology contained a read and write Thai (RWT) teaching/learning tool,
which was a multimedia web-based program made available in the Google Play Store. The software taught pronunciation, writing and reading in the Thai language.

An evaluation was also done in Malaysia to study the satisfaction of deaf learners who used an e-learning platform, named e-HearMe, which offered Information and Communications Technology (ICT) courses that were specifically designed for these learners (Nordin, Zaharudin, Yasin, & Lubis, 2013). The results indicated that the learners were satisfied with the online e-learning system since they were able to share knowledge and skills with teachers and other learners.

In the USA, a different e-learning system was made available for deaf adults with the aim of lifelong learning. The system was actually developed for both deaf and hearing learners. The system helped deaf learners to understand better the contexts presented to them (El-Soud, Hassan, Kandil, & Shohieb, 2010). Another example of e-learning software that has contributed to the education for the deaf was presented by Khwaldeh, Matar and Hunaiti (2007). The software proved useful for the interaction between teachers and deaf learners in Jordanian schools.

It has been stated that deaf learners experience more difficulties doing mathematics than hearing learners (Liu, Chou, Liu, & Yang, 2006). A study was conducted that presented a wireless technology to enhance the teaching and learning experience of deaf learners (Liu et al., 2006). The students demonstrated a positive response to the application and it proved helpful in their mathematical activities.

The preceding literature provides an encouraging perspective on the potential for assistive technology to improve the education of disabled learners. However, the literature also includes studies where assistive technology was not effective. For example, it has been noted that assistive technology has been very limited for students with cognitive and social deficits, and the lack of resources, both economic and social, is a common obstacle to using assistive technology (Kärnä-Lin, Pihlainen-Bednarik, Sutinen, & Virnes, 2007).

Another study investigated the effects of assistive technology as a compensatory tool for junior high school students with writing disabilities (Hetzroni & Shrieber, 2004). A computer was equipped with a word processor, which was the compensatory tool. It initially enhanced the students’ results by reducing spelling mistakes and reading errors. However, over time, the students’ spelling and reading mistakes actually increased because of a lack of concentration and fatigue from using the system.

Speech technology, in particular, has been used for learners with visual, hearing and physical disabilities (Koester & Mankowski, 2014). This technology enables machines to receive and
accept human speech as input and respond with human-like speech as output. It was found that the speech technology in this study was not successful because of grammatical errors produced by the technology. The study found that the development of speech technology was not yet complete and further research was required (Koester & Mankowski, 2014).

A different technology called Note-Taker was researched in a project called Note-Taker 3.0. It was for visually impaired students to enable them to take their own notes (Hayden, Astrauskas, Yan, Zhou, & Black Jr, 2011). Note-Taker was tested in a classroom and results indicated that it was very slow and not accurate enough for the students. In addition, it had problems with the operating system, which made it unreliable and further research was required.

In addition, the use of an electronic text tool, called eText, was explored for mathematics classes and visually impaired learners (Bouck & Weng, 2014). The eText used textual materials that were presented in various ways for supporting these learners. They found that a challenge faced by the teachers was the lack of information about the disabilities and the computers. The teachers needed support on the use of the computers and on how to present educational tasks and activities to these students. Combining technology with the curriculum textbooks was another challenge for the teachers (Bouck & Weng, 2014).

A pilot study was done on the use of assistive technology in Norwegian primary and secondary schools for disabled learners (Söderström, 2012). The assistive technology included computers, an eye-tracking software program and an enlarged keyboard (Söderström, 2012). However, learners had challenges with incompatible software and hardware, which contributed to a lack of interaction. In addition, teachers faced challenges such as uncertainty about their level of responsibility for the disabled learners, their lack of competency with the devices and insufficient preparation time for the practical activities.

Another study was conducted in schools in Michigan, USA to investigate the use of assistive technologies and the associated barriers for disabled learners and their teachers (Bouck et al., 2006). The assistive technologies used involved software and laptops. The results showed that the main problem was learners not being properly trained due a lack of knowledge on the part of the teachers and administrative staff at the schools.

Additionally, three-dimensional (3D) animated software has been used to teach mathematics to deaf learners (Adamo-Villani & Wilbur, 2008). The software was called Mathsigner and worked with a mouse and a keyboard, which allowed the learners to perform the tasks within the program. This included performing a sequence of goal-oriented activities that involved navigating to specific sections of the program, entering text, selecting and moving two-
dimensional (2D) objects, manipulating the view of the 3D avatar and changing the signing speed. The study showed that deaf learners took longer to complete the tasks on the software than hearing learners.

There are also studies presented in the literature that show mixed results from the use of assistive technology. For example, in some countries like Finland, assistive technology is easily accessible and widely used (Kärnä-Lin et al., 2007). Here, assistive technologies involve mobile phones and vision phones for playing, working and learning. However, even with this variety of assistive technology, the Finnish school system faced many challenges integrating students with special needs into normal classes. The challenges included changes and adjustments in teaching methods and practices, learners’ attitudes towards using assistive devices and materials and equipment used (Kärnä-Lin et al., 2007).

A survey that was conducted to evaluate the satisfaction of learners with various types of assistive technologies showed that there was a high level of satisfaction from some learners where assistive technology had helped them with school work, while others indicated a low level of satisfaction (Murchland, Kernot, & Parkyn, 2011).

A study conducted in Kenya looked at the use of mobile devices as an assistive technology for learners with visual impairments (Foley & Masingila, 2014). However, the challenges in using such devices included the lack of infrastructure in some parts of Kenya where there is unreliable or no electricity and the lack of knowledge about computerised equipment and software programs. Nonetheless, the authors concluded that the visually impaired learners showed a need for these devices and they were eager to learn how to use them.

Additionally, a study involving thirty children in six classrooms was conducted at an educational centre (Borgestig, Falkmer, & Hemmingsson, 2013). The centre had a computer room and other ICT resources including assistive devices. Some of the children stated that the assistive technology had helped them while others stated that they could not use the computers because of a low level of cognitive ability, lack of training and lack of proficiency with the assistive devices.

Another study was done on high school students with reading and learning disabilities (Chiang & Liu, 2011). The assistive technology was called Kurzweil 3000, being assistive reading software, which was used to assist learners to read texts, improve reading speeds and improve word pronunciation. Challenges included missing automatic grammar correction and teachers that needed more support and training (Chiang & Liu, 2011). The benefits included students being able to scan through books and texts and being able to engage with other students in the classroom. Similarly, a study involving students with reading disabilities was
conducted with post-secondary students (Schmitt, McCallum, Hennessey, Lovelace, & Hawkins, 2012). The assistive technology, called reading pen, improved the decoding and vocabulary skills of the students with learning disabilities. However, the assistive pen did not sufficiently improve the students’ understanding of the texts and more research was required to prove its effectiveness (Schmitt et al., 2012).

A different study was conducted on the use of assistive listening devices in schools that catered for pupils with hearing loss (Rekkedal, 2014). The devices used were teacher microphones and pupil microphones for an enhanced listening environment that aimed to increase participation in the classroom. Results indicated that teachers who had a positive attitude towards the devices integrated them better than teachers who had a negative attitude. The literature demonstrates that the use of assistive technology plays an important role in the education of learners with special needs. However, assistive technology does not automatically result in the improved education of disabled learners. There are studies that show positive results, negative results and mixed results. It is apparent that many factors are involved in the use of assistive technology, all of which require careful consideration. Thus, theories to guide the use of assistive technologies are necessary. The next sub-section presents the theories that are appropriate to guide the use of assistive technology in the study.

2.5.4 Learning theories and assistive technologies

2.5.4.1 Prominent learning theories in education: Review and selection

Learning theories explain how an individual acquires knowledge and understanding (Cottrill, 2009). This section provides a review of prominent learning theories in education that are appropriate to guide the use of assistive technology in the study. While there are many learning theories in the literature, four prominent theories appeared to be highly relevant to the study to guide learning with assistive technology, namely Behaviorism, Cognitivism, Constructivism and Connectivism.

Behaviorism explains that learning is accomplished when a proper response is demonstrated following the presentation of stimuli (Ertmer & Newby, 1993). Behaviorism originated from J.B. Watson (1878-1958) and was later adopted by B.F. Skinner (1904-1990) as a native language theory (Horowitz, 1992). Skinner believed that a learning outcome was achieved by an observable change in behaviour (Faryadi, 2007). In Behaviourism, the focus is not on the mental activities of learners but rather on performing certain behaviours (Crow & Tian, 2006). The theory looks at what learners do in response to an environmental signal instead of looking at how learners feel and think (Kay & Kibble, 2016). In Behaviourism, learning has
nothing to do with the mind but occurs through new behaviour or correct responses to stimuli (McDonald, Yanchar, & Osguthorpe, 2005). Terms that have been associated with Behaviorist learning include traditional learning, teacher-centred and passive learning (McDonald et al., 2005). As discussed by Fosnot (1996), teachers supporting the behaviorist theory spend time in developing well-structured curriculums on how best to assess, motivate and evaluate learners. Kay and Kibble (2016) speculate that learners in such instances do not think or reflect on learning but rather they are controlled by the teacher that requires them to complete tasks whenever they are needed to. In such instances, learners have to follow the teacher’s instructions, which can fail to promote critical thinking in learners.

In Behaviourism, the teacher has control of the learning environment by creating desired behaviour in learners and discouraging behaviours that are deemed to be undesired (Liu et al., 2006). Behaviorism is all about controlling the learning process and less about cognitive change within learners (Fosnot, 1996). Thus, Behaviorism may not be ideal for mathematics learning because the learners are mostly passive and react to stimuli (Liu, Qiao, & Liu, 2006). Some of the limitations of Behaviorism have been addressed by Cognitivism. Cognitivism has various prominent branches, including Piaget’s theory of Individual Cognitive Development, Vygotsky’s Theory of Social Cognitive Growth and Bruner’s Cognitive Constructivist Theory. While Behaviorist learning theories focus on the external behaviour of learners, Cognitivism focuses on the mental structures of learning in addition to changes in behaviour. Cognitive learning theory underscores how knowledge is acquired through storing, retrieving and processing information (Anderson, Reder, & Simon, 1997). Cognitivists focus on how knowledge is developed, how it is used in social settings and how it is processed in the brain (Craik, 1991). Piaget’s theory of Individual Cognitive Development linked cognitive growth with maturation. In an educational context, Piaget believed that children’s cognitive development passes through individual stages namely sensory-motor, pre-operational and operational stages (McCormack, 2009). Piaget’s theory has been criticised for proposing that learning happens after development. In contrast, Vygotsky believed that learning happens before development and that children learn through experience and symbolism (Donald, Lazarus, & Moolla, 2014). Vygotsky also believed that it is through social interaction that children learn from each other and from adults. Vygotsky’s theory looks at how children from infancy onwards construct shared meanings through social interactions with people such as adults, parents, other learners at school and teachers (Donald et al., 2014). Children learn by grasping what they
already know and adapting it with new information through social interactions. Nevertheless, Vygotsky’s descriptions of developmental processes have been criticised for, among other things, focusing more on the processes of development than the precise and measurable characteristics of each stage of development. Furthermore, Cognitivism views knowledge as independent of the learner where a teacher’s aim is to develop cognitive structures of the objective world in the learner. This view began to hold less credibility as time passed, leading to Constructivism.

Constructivism, while still viewing learning as occurring in the mind, viewed knowledge development as a subjective creation of meaning based on an individual’s past experiences. Constructivism continued to branch out from Piaget’s and Vygotsky’s theories on Cognitivism to posit that knowledge is not transmitted but constructed subjectively in the mind. Constructivism is a theory of learning and not a description of teaching and requires invention and self-organisation by the learner (Fosnot, 1996). This means that learners are allowed to raise their own questions, generate their own models and test them for viability.

Constructivists believe that learning cannot happen in a passive way. Instead of learners absorbing knowledge, they are active and they actively construct knowledge by taking part and interpreting ideas from recently gained experiences and knowledge (Eady & Lockyer, 2013; Packer & Goicoechea, 2000). Furthermore, Constructivist learners construct knowledge in their own minds where the teacher is the facilitator and provides ways that make information meaningful and relevant to learners (Slavin, 2000). The essence of Constructivism is that learners are given the opportunity to speak their mind, to make a hypothesis and test that hypothesis and consequently construct new knowledge (Tuwoso, 2016), which is also deemed to have positive effects on learning and academic attitude in classroom environments (Semerci & Batdi, 2015). Furthermore, Constructivists believe that learning cannot happen in a passive way. Instead of learners absorbing knowledge, they are active and they actively construct knowledge by taking part and interpreting ideas from recently gained experiences and knowledge (Eady & Lockyer, 2013; Packer & Goicoechea, 2000).

Thus, Constructivism has important implications for teaching and often emphasizes learner-centred teaching (Dagar & Yadav, 2016) where the focus of teaching is on the learner rather than on the teacher (Collins & Voc, 2008). Learner-centred (LC) teaching is a method of teaching that implies active engagement between the teacher and learner while minimising teacher dominance during the teaching process (Ngussa & Makewa, 2014). During LC teaching, learners are actively involved in the learning process; they replace and adapt their existing knowledge and understanding with deeper and more skilled levels of understanding (Kasim, 2014).

In comparison, a contemporary learning theory called Connectivism is a learning theory that was established mainly for e-learning (Goldie, 2016). Connectivism originated from Siemens
(2005) who stated that learning could be constructed through networking in a digital environment. Connectivism is about adopting connections in a social, cognitive and emotional era (Goldie, 2016). Siemens (2005) states that because Behaviorism, Cognitivism and Constructivism were created during a time of different technological contexts, the new generation of technology such as web 3.0 could replace learning models for greater relevance in education (Marhan, 2006).

Connectivism indicates that knowledge development is a cycle and the starting point is the individual within a network (Marhan, 2006). Knowledge is shared with communities or institutions which in turn feedback into the network to provide learning for the individual (Marhan, 2006). In simple terms, the starting point for learning to occur is when knowledge is activated by the learner by connecting and participating in a community such as online videos, wikis and other interactive systems.

In Connectivism, learners have to keep connecting to a network to share and find new information to develop ideas and beliefs (Kop & Hill, 2008). However, Connectivism does not explain the changes in knowledge development that a learner may experience during interaction with the social world, which Constructivism does (Kop & Hill, 2008). Furthermore, while Connectivism fosters knowledge development in a similar way to Constructivism, it may not be the appropriate theory for all subjects (Duke et al., 2013). For example, mathematics is a subject that requires mentoring, scaffolding and internalising concepts in terms of real world scenarios (Duke et al., 2013) and Connectivism does not support scaffolding in the same way as Constructivism does (Del Moral, Cernea, & Villalustre, 2013). In addition, Connectivism often only applies to those learners who have already developed the necessary skills to effectively search for and contribute to information on a network (Del Moral, Cernea, & Villalustre, 2013).

Importantly, Constructivism has been seen as a necessity in special education. This is supported by researchers such as Ernest (1992), Cobb (1994), Simon (1995), Collins and Voc (2008) and Seekola (2011). In addition, prior research has indicated that improving mathematics education for deaf learners requires learning to be interactive between the teacher and learners as well as enhanced through visual technology-based presentations (Agrawal & Morin, 2016). Thus, Constructivism is the most appropriate of the prominent learning theories reviewed for the study (Briede, 2016; Dewi & Harahap, 2016; Major & Mangope, 2012; Mihrka & Mihrka, 2014; Seekola, 2011). These authors demonstrate how learning mathematics in a Constructivist classroom facilitates learning, group work, active participation, problem-solving and critical thinking skills. Therefore, Constructivism provides
the most appropriate theoretical basis for the study, which proceeds on the premise that learning is an active, constructive process. Hence, the answer to Research Question One is Constructivism.

2.5.4.2 Appropriate assistive technology: Review and selection

Initially, the researcher scrutinised the literature for prior research that used mathematics software applications as assistive technology in similar research contexts. Thereafter, the researcher searched the internet for mathematics software applications. Both methods of searching resulted in a list of ten software candidates, namely Signing Math Dictionary, Math Signer, GeePerS*Math project, Master Maths, Math Whiz, Microsoft Mathematics, Adaptive Mind Math, RekenTest Software (RTS), Mathblaster and Geometer’s Sketchpad.

The software evaluation process for any study investigating the effects of software is very important for the success of the study (Dynarski et al., 2007). The main evaluation criteria for the mathematics software applications were the research objective, as stated in Section 1.5, and the potential suitability for a Constructivist classroom, being the selected learning theory. Then, subsequent evaluation criteria were: Is sign language supported? Are student grades supported? Are mathematics concepts supported? Does it have assessment features? Does it have tutorial features? Does it have learning features? Does it have video tutorials? Does it have selectable levels of difficulty? Does it have timed exercises? Does it have printable reports after each session? Is usage free? What is the availability of software? What are the installation options? What operating system is required? And what are the hardware requirements? Each software application was scrutinised based on these criteria as indicated in Table 2.

Table 2: Assistive technology evaluation

<table>
<thead>
<tr>
<th>Software</th>
<th>Sign language supported</th>
<th>Student grades supported</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signing Math Dictionary</td>
<td>American Sign Language (ASL) and Signed English (SE)</td>
<td>Grades 4-8 Kindergarten to 4th grade (K-4)</td>
</tr>
<tr>
<td>Math Signer</td>
<td>ASL</td>
<td>Grades 4-12 Kindergarten to 8th grade (K-8)</td>
</tr>
<tr>
<td>GeePerS*Math project</td>
<td>None</td>
<td>Grades 8-12 Kindergarten to 8th grade (K-8)</td>
</tr>
<tr>
<td>Master Maths</td>
<td>None</td>
<td>Grades 1-8 Kindergarten to 7th grade (K-7)</td>
</tr>
<tr>
<td>Math Whiz</td>
<td>None</td>
<td>Kindergarten to 8th grade (K-8)</td>
</tr>
<tr>
<td>Microsoft Mathematics</td>
<td>None</td>
<td>Grades 3-12</td>
</tr>
<tr>
<td>AdaptedMind Math</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>RekenTest Software (RTS)</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Mathblaster</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Geometer’s Sketchpad</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Mathematics concepts supported</td>
<td>Does it have assessment features?</td>
<td>Does it have tutorial features?</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>Addition, subtraction, division, multiplication, estimation, measurement, fractions</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Number concepts, decimals, fractions, addition, subtraction, division, multiplication, estimation, measurement, fractions</td>
<td>Pre-algebra, algebra, trigonometry, physics, chemistry, and calculus</td>
<td>Yes</td>
</tr>
<tr>
<td>Pre-algebra, algebra, trigonometry, physics, chemistry, and calculus</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Number sense, addition, subtraction, division, multiplication, estimation, geometry, algebra, fractions and decimals</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Addition, subtraction, division, multiplication, estimation, measurement, geometry, algebra, fractions and decimals</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Addition, subtraction, division, multiplication, estimation, measurement, geometry, decimal, money</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Addition, subtraction, division, multiplication</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Geometry</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
After considering all the criteria in Table 2 for each software application, the following was evident. Signing Math Dictionary offers signing in American Signed Language (ASL) and Signed English (SE); however, Namibian deaf learners mainly understand Namibian Signed Language (NSL). In addition, Signing Math Dictionary is only a signing dictionary of mathematics terms, and as such, it does not have any exercise features and has limited examples for each mathematics term. So, Signing Math Dictionary was not selected. Math Signer was not tested and not selected because the authors and contacts on the application’s web site did not respond after several attempts to make contact. GeePerS*Math project offers signing in ASL only and was not available to test via the Android app store even though the web site indicated that it was. Master Maths, Math Whiz, AdaptedMind Math and Math Blaster were not selected since they were not freely available and/or had features similar to the other applications evaluated. Microsoft Mathematics was not selected because it is more applicable to higher level grades like grade 8 to 12. The Geometer's Sketchpad was not selected because it offers mostly geometry-based tutorials.
Out of all the applications evaluated, RekenTest Software (RTS) was the most suitable because of its extensive design and potential to support most principles of Constructivism in a classroom, as indicated in Section 2.5.5. RTS was designed to adapt itself to a specific student, based on that student's learning. In addition, RTS was developed for both learners and teachers to make teaching and learning effective in mathematics. RTS enabled learners to practice, analyse and test arithmetic skills. The software offered problems ranging from very easy to difficult problems. Learners were also presented with a progress report for each session. Furthermore, the software was applicable to expose learners to arithmetic problems within a primary classroom setting and it matched the curriculum content of the grade three junior primary phase syllabus in Namibia. RTS also had the potential to foster a learner-centred approach by allowing learners to investigate the concepts provided by the software through exploration and discovery. Apart from supporting a learner-centred environment, RTS was user friendly and its interface was easy to use and straightforward for learners, which would motivate learners and encourage them to learn mathematics concepts independently and at their own pace. Thus, RTS was the most appropriate for studying the effects of assistive technology and suitable for the selected learning theory. Notably, RTS is not claimed to be designed and/or marketed as Constructivist software and by itself cannot be regarded as Constructivist software. However, it is regarded as a tool, like any other educational tool at a teacher’s disposal, that when embedded in a Constructivist classroom or learning environment can be used specifically in terms of Constructivist principles so that it can be regarded practically as Constructivist assistive technology by its use and not by its design. This answered Research Question Two.

Following are descriptions of some of the common features of RTS.

- **File menu option** – Indicates the different user groups for the software, being either Student or Teacher or Administrator. As shown in Figure 1, the main user of the program is the Student who would be practicing and solving problems on the software.

![Figure 1: RTS user groups](image-url)
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- **Task menu option** - Allows learners to start a session by customising their own problems based on their own level of learning under the “Show wizard” option, as shown in Figure 2. Learners may choose their level of difficulty as well as choose the amount of problems they want to work on. In addition, learners may further choose tasks that have already been created by the teacher under the “Select from list” setting or under “Task” in “Predefined” setting.

![Figure 2: Defining a Task](image)

- **Session menu option** – This is the starting point for a learner to customise his/her problems before practising or selecting from the list defined by the teacher. Starting a session indicates that a learner is ready to work on problems and they have to enter their names after clicking on the “Start session” button or the “Session” menu option as shown in the Figure 3.

![Figure 3: Starting a Session](image)

Once the learner begins, the RTS screen displays the student name at the bottom left of the screen, the type of task the learner is practising on and the number of problems the learner chose.

- **Session dialog box** – This enables a learner to customise their learning. The different settings are also applicable to the teacher who may set up advanced tasks to be accessible to the learners on their laptops. So, the mathematics teacher could define tasks on each individual laptop to be accessed by the learners for classwork activities and exercises.

When defining a session, the first setting indicates the range of values to work with as indicated in Figure 4. The second setting indicates the concepts to work with, in Figure 5. For
the study, learners are expected to work with whole numbers, which are numbers without decimal places or fractions. The third setting indicates the arithmetic operations to work with, in Figure 6. The fourth setting indicates the difficulty level to work with, in Figure 7. The fifth setting indicates how much to practice, in Figure 8. The sixth setting indicates the feedback selection, in Figure 9. The seventh setting indicates the number of players selection, in Figure 10. The eighth setting indicates the time selection, in Figure 11 and the ninth setting indicates the number of problems selection, in Figure 12.

![Figure 4: Selection of values](image.png)
Figure 5: Selection of concepts

Figure 6: Selection of arithmetic operations
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Figure 7: Difficulty level

Figure 8: Practice amount
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Figure 9: Feedback selection

Figure 10: Number of players selection
Figure 11: Time selection

Figure 12: Number of problems selection
• **Session screen** – Provides the interface for learners to construct their knowledge. An example is Figure 13.

![Figure 13: Two-player screen](image1)

• **Results screen** – Provides the results of the learning activities for learners to reflect on their answers and construct their knowledge. An example from a two-player session is Figure 14. An example from a one-player session is Figure 15.

![Figure 14: Two-player screen](image2)
2.5.5 The selected learning theory and the selected assistive technology

2.5.5.1 Overview of traditional classroom principles

Traditional teaching and learning methods can be described as teacher-centred and are based on a model of an active teacher and passive learners (Mascolo, 2009). The goal is for the teacher to transfer knowledge to the learners whilst in control of the lesson plan to achieve lesson objectives. The approach focuses on the teacher who has control of the knowledge or what is to be learned by learners and the learners remain passive, listen and respond according to the teacher’s instructions. The traditional classroom lacks the principles of Constructivism in the sense that teachers control the learning process, tell and give direct instruction to learners without learner involvement. The role of the learners is to listen, take notes, do exercises and answer the teacher’s questions and learners typically use textbooks as their main learning tool.

The arrangement for the traditional classroom involves the teacher standing in front of the classroom while learners sit facing the teacher. The presenting of concepts such as addition, subtraction, multiplication and division are the teacher’s responsibility while learners listen passively with the exception of responding to questions asked by the teacher. The teacher informs them about the learning goals and objectives, shows examples, corrects during presentation of the content and takes learning objectives from the curriculum. Much of the assessment is done when learners submit homework the following day.
Although learners may be seated in groups, tasks such as classroom exercises are done individually and they may be assessed only at the end of every lesson. Learners memorise what they are taught and there is little or no attention to social development. In addition, the concepts are taught in their own discipline without any integration with other subject areas such as social science or art. Hence, learners in the traditional teaching and learning environments learn through their teacher with little collaboration and cooperative learning.

2.5.5.2 Overview of Constructivist classroom principles

In contrast to the traditional classroom principles, Table 3, provides eighteen principles of Constructivism from the literature (Murphy, 1997). In the subsequent sections after Table 3, each principle is explained in relation to a mathematics classroom and the RekenTest Software (RTS), which was the selected assistive technology for the study’s empirical work.

Table 3: Eighteen principles of Constructivism (Murphy, 1997, pp. 11-13)

<table>
<thead>
<tr>
<th>No</th>
<th>Key principles of Constructivism (Murphy, 1997, pp. 11-13)</th>
<th>Other relevant references</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>“Multiple perspectives and representations of concepts and content are presented and encouraged”.</td>
<td>(Honebein, 1996; Moeller &amp; Reitzes, 2011; Ozgun-Koca, 1998)</td>
</tr>
<tr>
<td>2.</td>
<td>“Goals and objectives are derived by the student or in negotiation with the teacher or system”.</td>
<td>(Paulson &amp; Bauer, 2011; Pintrich, 2000; Schutz &amp; Lanehart, 1994)</td>
</tr>
<tr>
<td>4.</td>
<td>“Activities, opportunities, tools and environments are provided to encourage metacognition, self-analysis, self-regulation, self-reflection &amp; self-awareness”.</td>
<td>(Du Toit &amp; Kotze, 2009; Gordon, 1996; Sprague &amp; Dede, 1999)</td>
</tr>
<tr>
<td>6.</td>
<td>“Learning situations, environments, skills, content and tasks are relevant, realistic, authentic and represent the natural complexities of the ‘real world’”.</td>
<td>(Gulikers, Bastiaens, &amp; Martens, 2005; Reeves, Herrington, &amp; Oliver, 2002; Van Den Heuvel-Panhuizen, 2003)</td>
</tr>
<tr>
<td>7.</td>
<td>“Primary sources of data are used in order to ensure authenticity and real-world complexity”.</td>
<td>(Barnett, Lodder, &amp; Pengelley, 2016; Carnine &amp; Lehr, 2005; Clabough, 2012)</td>
</tr>
<tr>
<td>No.</td>
<td>Key principles of Constructivism (Murphy, 1997, pp. 11-13)</td>
<td>Other relevant references</td>
</tr>
<tr>
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<td>---------------------------------------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>8.</td>
<td>“Knowledge construction and not reproduction is emphasized”.</td>
<td>(Jonassen, 1994; Major &amp; Mangope, 2012; Nelissen &amp; Tomic, 1993)</td>
</tr>
<tr>
<td>10.</td>
<td>“The learner’s previous knowledge constructions, beliefs and attitudes are considered in the knowledge construction process”.</td>
<td>(Ertl &amp; Mandl, 2008; Kara, 2009; King, 1994)</td>
</tr>
<tr>
<td>11.</td>
<td>“Problem-solving, higher-order thinking skills and deep understanding are emphasized”.</td>
<td>(Krathwohl, 2002; McTighe &amp; Seif, 2014; Zanzali &amp; Lui, 2000)</td>
</tr>
<tr>
<td>12.</td>
<td>“Errors provide the opportunity for insight into students’ previous knowledge constructions”.</td>
<td>(Lin &amp; Tsai, 2013; Rach, Ufer, &amp; Heinze, 2013; Seifried &amp; Wuttke, 2010)</td>
</tr>
<tr>
<td>13.</td>
<td>“Exploration is a favoured approach in order to encourage students to seek knowledge independently and to manage the pursuit of their goals”.</td>
<td>(Brown, 2008; Pramling Samuelsson &amp; Johansson, 2006; Pundir &amp; Surana, 2016)</td>
</tr>
<tr>
<td>14.</td>
<td>“Learners are provided with the opportunity for apprenticeship learning in which there is an increasing complexity of tasks, skills and knowledge acquisition”.</td>
<td>(Collins, Brown, &amp; Newman, 1988; Dennen &amp; Burner, 2008; Oriol, Tumulty, &amp; Snyder, 2010)</td>
</tr>
<tr>
<td>16.</td>
<td>“Collaborative and cooperative learning are favoured in order to expose the learner to alternative viewpoints”.</td>
<td>(Dillenbourg, 1999; Matthews, Cooper, Davidson, &amp; Hawkes, 1995; Zakaria, 2009)</td>
</tr>
<tr>
<td>17.</td>
<td>“Scaffolding is facilitated to help students perform just beyond the limits of their ability”.</td>
<td>(Anghileri, 2006; McMahon, 2000; Mishra, 2013)</td>
</tr>
</tbody>
</table>
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2.5.5.3 Principle One: “Multiple perspectives…”

“Multiple perspectives and representations of concepts and content are presented and encouraged”

Multiple representations is the expression of ideas and concepts that provide the same information in more than one form (Ozgun-Koca, 1998). Multiple representations can enhance learning and give learners the opportunity for deeper insight (Honebein, 1996). Examples of multiple representations include text and words, diagrams, drawings, audio and animations (van der Meij & de Jong, 2004). The principle is vital in a Constructivist environment because it provides learners with deep learning skills and enhances their motivation to learn, which is often not supported in traditional classrooms (Moeller & Reitzes, 2011).

In a mathematics classroom, concepts expressed in multiple representations, including symbolic representations such as numbers that articulate different meanings (Panasuk & Beyranevand, 2011) assist and guide learners to explore other ways of solving problems (Amoonga, 2008; Dreher, 2015; Gagatsis & Elia, 2005; Honebein, 1996). Practically, teaching the concept of addition such as getting the sum of two values can be done through a drawing of objects or with numbers from the textbook. Furthermore, using an example from Makonye (2014), the following tasks can be represented differently. A first representation or perspective could be to determine $4+0$ and $4+3$ and $4+3+3$ to yield $4+0=4$, $4+3=7$ and $4+3+3=10$. Another representation could be in words, such as 4 plus zero threes, 4 plus one three and 4 plus two threes. Through these different representations or perspectives, learners are able to connect links and solve the same problems in different formats (Makonye, 2014).

Within RTS alone, the principle is not supported since it only represents problems numerically. However, combined with the Constructivist classroom, the principle can be supported. During the class sessions, the teacher may request learners to illustrate the mathematics problems in different representations together with RTS. For example, if RTS displays $7 + 3 = 10$, one learner may be required draw circles or lines on the chalkboard to represent the problem while the other learners may be required to represent the problem in words or in Namibian Signing Language. This is also an effective strategy to teach learners with different learning styles. In this way, learners are exposed to different representations of the concepts of addition, subtraction, multiplication and division as part of learning in a Constructivist classroom environment to reach their goal of understanding the four operations.
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In addition, RTS itself is a different medium or representation compared to a textbook or a whiteboard and it represents a much wider set of examples than the textbook or teacher. Therefore, the concepts and contents such as addition are represented far more extensively, thoroughly and dynamically than the textbook representation, which allows learners to better construct their knowledge. In this way also, the RTS representation can support this principle of Constructivism.

2.5.5.4 Principle Two: “Goals and objectives…”

“Goals and objectives are derived by the student or in negotiation with the teacher or system”

It has been acknowledged that learners often set goals in their learning, monitor those goals and regulate their cognition and motivation to reach those goals (Pintrich, 2000). Learning goals may be macro goals or micro goals (Paulson & Bauer, 2011). A macro goal may be completing an entire assignment before deadline date and achieving a pass mark of eighty percent. Micro goals may involve reading a chapter from a textbook within ten minutes (Paulson & Bauer, 2011). Micro goals are useful for achieving difficult larger tasks or macro goals by breaking them down into manageable chunks (Schutz & Lanehart, 1994).

In a Constructivist classroom, overall learning goals and objectives should still be determined by the teacher, being a competent subject expert. For example, the teacher determines what learners should know or learn about a particular subject in a certain timeframe. Then, the teacher, also based on an assessment of the learners’ current level of knowledge, may discuss and negotiate with the learners how to break the topic up into smaller manageable learning tasks, their sequence and deadlines (Moss & Brookhart, 2012).

On RTS, the principle is supported by learners being able to choose a variety of granular exercises. For example, the teacher can determine that by the end a week, learners should be able to add and subtract two whole numbers of certain sizes. Learners can then negotiate with the teacher about or set their own goals for how they wish to learn the overall goal. They could alternate daily between the two topics or learn either in one day or another. RTS supports this environment. In RTS, learners can choose how they want to achieve this goal and the steps and routes they want to take since RTS is very flexible and allows the learner to choose the type of problems, difficulty level and time to complete, in addition to many other settings. For example, learners can choose to practise addition of whole numbers with values less than ten only until this is mastered and, thereafter, values less than one hundred and so on until the required level is mastered.
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In addition, learners can work in groups with assistance of the teacher. In their groups, they are empowered to choose what to do, how to solve the problems and what questions to ask to solve a problem. For instance, during an activity with RTS, learners may determine their own goals by first solving those problems that they find easier to solve then the teachers may further encourage them to solve more difficult problems as they explore with RTS. At the end of an activity, the learners can evaluate his/her achievement through the self-assessment report from RTS.

2.5.5.5 Principle Three: “Teachers serve in the role of guides...”

“Teachers serve in the role of guides, monitors, coaches, tutors and facilitators”

In a Constructivist classroom, teachers serve as guides, facilitators and tutors, which is different to traditional classroom teaching (Lai, 1993). The change from an instructor to a facilitator promotes understanding, thinking and reasoning abilities in learners (Doyle, 2007). In addition, it encourages collaboration and helps learners to build their knowledge during the learning process (Alzahrani & Woollard, 2013).

As a guide, facilitator and tutor, the teacher poses questions and creates an environment where learners are able to ask questions (Har, 2005; Major & Mangope, 2012) rather than only transmitting knowledge to the learners, which occurs in traditional teaching. This principle also applies to LC teaching where the teacher creates dialogue, engages learners and develops active learners rather than just conveying information to them (Alsardary & Blumberg, 2009; Ang, Gonzalez, Liwag, Santos, & Vistro-Yu, 2001; Li, 2016).

For example, teachers in a mathematics class could pose questions to learners, let them explain their thinking and further engage with them where they need further clarity (Wigley, 1992). The role of the teacher is to provide an opportunity for learners to explore and learn deeply through two-way communication (Li, 2016). Another example could be a teacher giving an exercise requiring learners to match definitions of concepts as a class activity. After the learners complete the exercise, the teacher would then review the answers with the class and engage in questions as a coach and facilitator to ensure the learners understand the terms and definitions before proceeding to the next topic.

Moreover, in a Constructivist mathematics class, the role of the teacher is to facilitate, challenge and encourage learners (Wachira, Pourdavood, & Skitzki, 2013). The teacher first explains the concept and methods and allows questions during the explanation. Thereafter, the teacher encourages learners to work in small groups giving them related tasks to work on. The teacher engages with the learners, allowing them to reflect and discuss the tasks and
provides further explanations where required until the learners have developed the necessary connections between their previous knowledge and the introduced concepts and methods. On RTS, learners can work in groups, discuss and explore with their peers. The teacher can be a facilitator, tutor and guide, assisting learners to grasp the concepts by using the software. For example, learners may be presented with two-digit addition, put into groups and each group encouraged to work together to solve the two-digit addition problems. While learners reason and discuss the problem in their groups, the teacher visits each group, encourages every learner to be engaged in the activity and facilitates where there are difficulties. Each group can present their workings to the whole class and the facilitator can allow learners to defend their solutions while reviewing their answers through coaching and tutoring to make sure the learners have understood the concepts.

Rather than direct instruction and dominating of a lesson, the teacher challenges the learners through questioning, refrains from giving correct answers and provides assistance if needed. An activity may consist of a teacher presenting difficult problems from RTS on the chalkboard. Learners are expected to actively engage in discussions with their teacher. The teacher acts as the facilitator for learners to take control of their learning without getting direct answers from the teacher. As a facilitator, the teacher guides the learners to the correct solutions, which helps them to construct new knowledge without giving immediate answers. The teacher walks around to the groups to observe and see how learners are solving the problems. If learners are struggling to get the correct answer on RTS, the teacher asks questions, provides hints and suggests supporting exercises on RTS rather than giving the correct answer so that learners solve the problems on their own.

2.5.5.6 Principle Four: “Activities, opportunities, tools and environments...”

“Activities, opportunities, tools and environments are provided to encourage metacognition, self-analysis, self-regulation, self-reflection and self-awareness”

Metacognition can be defined as one’s knowledge and awareness of one’s own cognitive or thinking processes (Anderson & Kanuka, 1999). It is a learner’s ability to monitor, evaluate and regulate their own learning (Karaali, 2015). It involves a learner’s awareness of his/her decisions on what to include and what not to include when completing a task (Erskine, 2010). Metacognition helps learners to succeed because it is associated with setting a plan and strategy to achieve a goal (Little, 2009; Livingston, 2003) or to try different approaches to solving problems (Hott, Isbell, & Oettinger, 2014). Metacognition can be improved through
classroom activities that allow learners to perform think-aloud and self-checks and analyses (Hott et al., 2014).

Self-analysis and self-regulation are processes where learners monitor and evaluate the quality of their thinking and behaviour during a learning process as well as look for strategies that could improve their understanding and skills (McMillan & Hearn, 2008). Self-analysis informs learners about their current learning and their required learning to achieve given outcomes (McMillan & Hearn, 2008). Self-analysis and self-regulation provide room for improvement and revision (Warner, Chen, & Andrade, 2012). They include self-questioning, monitoring and evaluation for information about their cognitive processes to facilitate learning (Montague, 2008). For example, in a study, third grade learners’ self-analyses were shown to improve their mathematics learning (Brookhart, Andolina, Zuza, & Furman, 2004).

Self-reflection can be defined as procedure that a learner undertakes to look back on his or her previous learning experiences and what transpired then to enable new learning to occur (Lew & Schmidt, 2011). It is also defined as thinking about one’s own experiences to create awareness of thoughts, values and actions and to consider alternatives to problems (Roberts & Westville, 2008). Self-reflection is valued in mathematics education (Johnson, 2009) and has shown to be effective (Odafe, 2007).

Self-awareness has been described as one’s ability to think about, talk about and define one’s own feelings or actions (Flavian, 2016). In an educational context, self-awareness has been described as one’s self knowing about how to solve a problem or how to go about completing a task (Karaali, 2015). Self-awareness enables learners to actively identify, process and solve problems on a given task (Morin, 2011).

Teachers should encourage the use of activities and tools that enable learners to think, experience and reflect on what they have learned, which is often not supported in the traditional classrooms (Du Toit & Kotze, 2009; Gordon, 1996). This promotes understanding and creativity to improve metacognition and reflection. Furthermore, metacognition, experience and self-reflection can be achieved through the use of tools such as multimedia. In these environments, learners are provided with the opportunity to think, reflect and monitor their own learning processes (Gordon, 1996).

On RTS, metacognition, self-analysis, self-regulation, self-reflection and self-awareness are encouraged in an environment where learners can practise and think about their own learning as they proceed through the problems. The assessment option available on the software gives learners the opportunity to analyse their own understanding. RTS is very flexible, allowing learners to self-regulate their learning as they proceed from their current competencies to new
competencies. RTS helps learners reflect on what they have learned before they are presented with new problems and after they have attempted them. The interface of RTS encourages learners to become more self-aware of their own learning as they develop strategies for solving the problems and proceed to more difficult challenges. Furthermore, during the group activities on RTS, learners engage with one another as well as with RTS and learners make instructional decisions such as using the right settings and steps needed to solve the problems. Thus, RTS provides activities, opportunities and the environment to support these principles as learners are exposed to their own thought processes and those of the other learners in the group.

2.5.5.7 Principle Five: “The student plays a central role...”

“The student plays a central role in mediating and controlling learning”

Learners mediate learning when they are active in the learning process and make sense and meaning of received information. There should be active engagement between the learner and the teacher as part of a Constructivist learning environment (Presseisen & Kozulin, 1992; Zulu, 2016). In these learning environments, learners tend to be active and have control of their own learning (Kasim, 2014; Kay, 2001). Although a teacher initiates the teaching process, the learners are placed at the centre of the learning through collaborating learning, teacher facilitation and authentic instructions (Singh, 2011). For example, after being given an overall outcome, learners chose their content starting points and whether they learn individually or in groups. They can also make decisions on the kind of materials and tools to use, which is usually the responsibility of the teacher in a traditional classroom.

On RTS, learners can take ownership of their learning instead of waiting on the teacher for directions. Learners can choose what content to practice and at what level. In addition, learners can explore the activities provided on the software. The support of group work enriches their abilities and thinking skills through the many tasks presented. In these aspects, learners mediate and are in control of their own learning. For example, the teacher usually initiates the lesson, giving examples of the concepts and then asks learners to work on these in RTS. Learners may choose to work on simple tasks, complex tasks or a combination of the two. This permits learners to select diverse problem strategies from the software and understand how they approach those problems. They become responsible for their own learning and in control of using the software. The choice of problems contributes to learner control and becoming their own learning advocates. It encourages them to make decisions and to be independent.
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2.5.5.8 Principle Six: “Learning situations, environments, skills...”

“Learning situations, environments, skills, content and tasks are relevant, realistic, authentic and represent the natural complexities of the 'real world'”

In science education, relevant learning means learning involving real world problems that are significant to a learner’s life (Bokar, 2013). For example, this may involve providing mathematics content to grade three deaf learners using shapes and figures that can be found in the immediate environment such as stones or sticks (Ministry of Education, 2014).

Authentic learning is closely aligned to relevant learning and relates to knowledge and skill development using real life contexts (Gulikers, Bastiaens, & Martens, 2005). Authentic tasks are those that refer to the real world (Reeves, Herrington, & Oliver, 2002). The use of the term authentic task in mathematics contexts represents problems that could be encountered in real life. In a Constructivist mathematics class, authentic tasks are those presented as real-world problem solving activities (De Corte, Verschaffel, & Greer, 2000).

Similarly, a realistic task in mathematics means that learners are presented with content involving daily life problem situations that make sense to them (Peters, 2016; Van Den Heuvel-Panhuizen, 2003). Learners need to be presented with tasks that not only have meaning inside the classroom but outside too (Lowrie, n.d.). These types of problems engage learners in mathematics education (Van Den Heuvel-Panhuizen, 2003).

The classroom environments where learners are engaged in activities and tasks that they would encounter outside the classroom setting promotes thinking, problem solving and construction of meaning (Maina, 2004). For example, a teacher can present the school’s tuckshop menu to teach students addition and subtraction (Furner, Yahya, & Duffy, 2005).

RTS offers mathematics problems that are applicable to primary education level. The tasks presented offer curriculum appropriate activities such as addition, subtraction, multiplication and division which are all relevant for grade three learners. The problems encourage learners to think, solve and see meaning, which can be applied outside classroom environment. For example, the money function in RTS helps learners understand that addition or subtraction can be applied outside of the school if one has to go and buy something at the tuckshop. In this way, learners are provided with the opportunity to practise realistic and authentic real-world tasks.

In addition, authentic learning tasks happen through social engagement (Woo, Herrington, Agostinho, & Reeves, 2007). Using RTS, learners can come up with their own real-world scenarios from the tasks displayed on the software. The teacher can facilitate the tasks
creating an environment where learners are able to understand how problems can be applied outside classroom setting and in real-world scenarios. Real-world scenarios help learners to see the importance of what they are learning and at same time enhance their comprehension of concepts (Chrestensen, 2007). During these activities, learners are given the opportunity to understand the concepts outside their school environment and apply it in their daily lives as part of relevant, realistic and authentic assessment.

2.5.5.9 Principle Seven: “Primary sources of data...”

“Primary sources of data are used in order to ensure authenticity and real-world complexity”

Primary sources of data allow learners to develop their critical thinking and own meaning especially in mathematics (Barnett, Lodder, & Pengelley, 2016). Primary sources of data can engage learners and encourage a collaborative environment for knowledge construction (Clabough, 2012). It helps learners generate ideas about the real world which promotes authentic learning (Brooks, 1999). Primary sources of data may include photographs, cartoons, audio recordings and artefacts (Clabough, 2012). Traditional classrooms often provide data taken from textbooks (Kussumua, Iída Tavita Jurda Tomas, 2007). This is not always the case in a Constructivist mathematics class. For example, a mathematics teacher in a Constructivist class may use historical reports or data from newspapers (Carnine & Lehr, 2005).

RTS does not provide access to any repositories of primary data. However, it can be used in conjunction with primary data and manipulatives. For example, a teacher can use coins as a primary source of data and the learners can work with the coins to add and subtract in conjunction with the money sums on RTS to replicate real-world purchasing or shopping scenarios. The teacher may also use primary sources of data such as newspaper and magazine articles describing simple mathematical issues that the learners can understand. The teacher’s role is to ensure that the sources of data are aligned with the current concept studied so that learners are aware of the authenticity of the tasks and how can be applied in real-world settings.

2.5.5.10 Principle Eight: “Knowledge construction...”

“Knowledge construction and not reproduction is emphasized”

Knowledge construction involves active learning where experiences that learners already have are used to develop new knowledge structures often through interactivity, collaboration
and engagement (Jonassen, 1994). In order for knowledge to be constructed, lessons have to be planned in such a way that learners are actively engaged in tasks and can reflect on them based on their previous experiences (Jonassen, 1994; Major & Mangope, 2012). Learners construct meaning and knowledge through their own discoveries, experiments and active interactions (Nelissen & Tomic, 1993). Knowledge is similarly constructed through technology as an additional tool for knowledge enhancement (Dhindsa & Emran, 2006). Technology can facilitate knowledge construction by allowing learners to work in groups as well as by creating dialog with the teacher as a form of assistance, guidance and facilitation (Comeaux & McKenna-Byington, 2003).

On RTS, knowledge is constructed through active participation and learner interaction with new and existing ideas. It allows learners to actively participate and engage in each task displayed and apply what they have learnt in class, in groups and individually. Furthermore, the various levels of difficulty and feedback options provided in RTS support knowledge construction where the knowledge that learners already have is used to develop new knowledge structures. On RTS, learners have the opportunity to check their answers after every task completed. If they see that their answers are wrong, they can discuss it within their groups and with the teacher to understand where they made the errors and how to construct the required knowledge from their current knowledge base.

2.5.5.11 Principle Nine: “Construction takes place...”

“Construction takes place in individual contexts and through social negotiation, collaboration and experience”

Social negotiation, collaboration and the use of experience are achieved in a Constructivist classroom by learners working together in a community of peers and their teacher, where meanings are socially negotiated (Ernest, 1992; Pantel, 1997). A Constructivist classroom environment should allow collaboration and social negotiation for learners to share ideas with other learners and the teacher as the expert (Har, 2005; Voigt, 1994). For learners to construct knowledge, collaboration and social interaction are important values that should occur in the class, which is in contrast to traditional classrooms where students learn individually. In a Constructivist classroom, learners are exposed to the opinions and ideas of fellow learners and teachers.

Learning is typically active where learners negotiate new understanding from what they have experienced in the past (Amineh & Asl, 2015). Social negotiation, collaboration and use of prior experience facilitates knowledge construction and includes questioning, rehearsals and
elaboration in the classroom (Kreijns, Kirschner, & Jochems, 2003). In addition, it promotes involvement, problem solving skills, critical thinking skills and achievement (Raman & Ryan, 2004).

For example, learners can be arranged in groups for collaborative learning and social negotiation in a mathematics class (Rowe, 2002). Learners can be presented with tasks that allow them to listen to, explain to, ask questions of, clarify with, provide evidence to justify their solutions and give help and feedback to other group members. Within the Constructivist setting, learners construct knowledge by participating in the discussions, critically analysing their own ideas in relation to those of other learners, making contributions, giving explanations and presenting arguments.

In RTS, social negotiation, collaboration and the use of experience is supported by group session activities for learners to construct knowledge. For example, learners can be arranged in small groups with each computer having RTS installed. As part of collaborative learning, learners work together in groups on the problems provided by the software, they negotiate the questions by sharing their own ideas and opinions and share their experiences involving similar problems. The learners work collaboratively to analyse and reflect on what they have learned as part of social negotiation to achieve their goal, which is submitting the correct answer.

2.5.5.12 Principle Ten: “The learner's previous knowledge constructions...”

“The learner's previous knowledge constructions, beliefs and attitudes are considered in the knowledge construction process”

In a Constructivist learning environment, prior knowledge plays an important role for new knowledge construction and learning (Ertl & Mandl, 2008). The process of knowledge construction involves new information extending existing knowledge by adding new details and ideas to draw relationships from information already held (King, 1994). For example, planning and setting up new learning tasks using concepts learners already know (Campbell & Campbell, 2008). Learners’ beliefs and attitudes should also be considered. A positive attitude toward any learning content improves a learner’s ability to solve problems as well as acquire knowledge (Kara, 2009). If learners’ attitude towards learning mathematics is negative, then they are not likely to construct new meaning in the class (Colgan, 2014).

In RTS, learners can use what they already know to try and solve different levels of problems. This includes their prior knowledge from textbooks and traditional teaching. As they proceed into more difficult learning levels they have to construct new knowledge based
on their prior knowledge to solve those problems. In addition, if the software is easy to use it encourages a positive attitude towards learning (Alabdullaziz, Alanazy, Alyahya, & Gall, 2011).

RTS provides feedback to learners whether an answer is wrong or right, which supports them until they have mastered the concepts. In addition, the RTS interface is interactive and a report is provided at the end of each session for learners to evaluate themselves, which further encourages them. It has been mentioned in a study that learners believe that learning mathematics is much easier with technology (Adamides & Nicolaou, 2004). This could foster positive attitudes and confidence. Before the introduction of a new concept, the teacher may start the lesson by asking questions to find out what the learners already know and think about the topic or concept. The rest of the lesson and exercises on RTS can be based on this knowledge as the departure point so that the learners can use previous knowledge constructions, beliefs and attitudes in knowledge construction process.

2.5.5.13 Principle Eleven: “Problem-solving, higher-order thinking skills...”

“Problem-solving, higher-order thinking skills and deep understanding are emphasized”

Problem solving is the process where one uses knowledge and thinking skills to reach a solution (Yang, 2000). In Constructivist learning environments learners are required to think and make decisions based on activities and tasks given during the learning process (Zanzali & Lui, 2000).

Higher-order thinking skills require greater cognitive processing as opposed to just remembering facts (Collins, 2014). Higher-order thinking skills include, in ascending order, analysis, synthesis and evaluation and each requires mastery of the previous level (Krathwohl, 2002). This means breaking down complex materials into parts and combining previous levels to make judgements that include critical, logical, reflective, metacognitive and creative thinking (King, Goodson, & Rohani, 1998), which are required when learners come across unfamiliar problems or questions. In a Constructivist mathematics classroom, higher-order thinking skills could mean using abstractions, formulas, equations or algorithms in new situations (King et al., 1998). For example, to promote higher-order thinking skills in mathematics, learners could explain the derivation of a formula instead of memorising it (al - Kafarna, 2015).

Deep understanding refers to concepts that are well-connected and well-represented in a child’s mind (Zirbel, 2006). Learners are able to put pieces together insightfully to solve a problem. Deep understanding may occur when learners are able to explain concepts in their
own words, interpret by making sense of data through images and stories, apply what they know in new contexts, demonstrate perspective by seeing the big picture, have self-knowledge by showing metacognitive awareness and reflect on the meaning of the concepts (McTighe & Seif, 2014). In addition, learners can also elaborate by writing steps of a problem with answers which is more efficient to further their understanding than listening only (Sheie, 2016).

Using RTS, problem-solving, higher-order thinking skills and deep understanding are facilitated by learners’ being able to evaluate and analyse their own understanding of the mathematical concepts as they work in groups to solve progressively varied and more difficult problems.

2.5.5.14 Principle Twelve: “Errors provide the opportunity...”

“Errors provide the opportunity for insight into students' previous knowledge constructions”

In mathematics, an error occurs when a solution to a problem differs from the correct solution to that problem (Don, 2011). While errors occur on a daily basis through the learning process, they occur in different forms (Xie & Jiang, 2007). For instance, learners can make errors through carelessness (Gardee, 2015) or it may be that a learner has not understood or failed to grasp a certain mathematics concept, technique or problem (Radatz, 1980). However, errors are a significant part of many, if not all, learning processes (Lin & Tsai, 2013; Rach, Ufer, & Heinze, 2013). In addition, making errors in mathematics are an integral part of learning the subject (Ingram, Pitt, & Baldry, 2015). Errors provide opportunities for insight into students' previous knowledge constructions and can be used as motivation for metacognition, discussion and self-reflection of previous knowledge and how to move to new knowledge. If constructive feedback is given on children’s errors, then they are able to analyse and reflect on how to improve on the next problem (Seifried & Wuttke, 2010). This could be done through group discussions that include arguments, explanations and justifications. This not only helps learners to correct the error but also to construct new knowledge from the base of prior knowledge through collaboration and social negotiation, which is part of learning in a Constructivist environment (Owusu, 2015).

In addition, teachers in a mathematics class could use previous exercises with errors and ask learners to identify those errors as part of a class activity (Ingram et al., 2015). Sapire, Shalem, Wilson-Tompson, and Paulsen (2016) further encouraged continuous assessment of learners during the teaching process to understand if learners are grasping the new information and correcting their mistakes. Such engagement promotes knowledge construction.
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On RTS, errors also provide opportunities for insight into students' previous knowledge constructions. RTS allows a learner to choose instant feedback or delayed feedback with the correct answer to a problem. This provides the learner and teacher with an opportunity to understand the learner’s current understanding and thought processes used to attempt to solve the problem, and importantly how to change those to obtain the correct answer. This is further supported as learners choose to attempt ever more difficult problem levels. The instant feedback in RTS enables the learners and teacher to quickly identify areas of the students’ previous knowledge constructions that require attention.

2.5.5.15 Principle Thirteen: “Exploration is a favoured approach...”

“Exploration is a favoured approach in order to encourage students to seek knowledge independently and to manage the pursuit of their goals”

Constructivist education requires exploration for improved knowledge construction (Pundir & Surana, 2016). It enables learners to make their own observations while receiving guidance from a teacher during the learning process and it encourages learners to solve their own problems. This was also acknowledged by Brown (2008) who indicated that learners learn more by doing and exploring than observing.

Learners can acquire knowledge through play, exploration and their interaction with the environment, which can also be the basis of teaching and learning processes in mathematics (Pramling Samuelsson & Johansson, 2006). The focus would be to create activities that encourage learners to search, manipulate, attempt and experience mathematics problems that are part of daily life activities (Bose, Tsamaase, & Seetso, 2013). In addition, discovery learning in web-based learning is when learners branch from one term to another, which provides learning enhancement (Shelly, Cashman, Gunter, & Gunter, 2006).

On RTS, learners can explore different types of tasks such as whole numbers, decimals, tables, percentages, fractions and money, different types of problem value ranges such as values less than ten, less than twenty, and others, different types of problems such as addition, subtraction and others, different levels of difficulty, different feedback options, problem solving with one or two players, different lengths of time and different numbers of questions per exercise. All these features encourage students to explore, seek knowledge independently and to manage the pursuit of their goals.
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2.5.5.16 Principle Fourteen: “Learners are provided with the opportunity...”

“Learners are provided with the opportunity for apprenticeship learning in which there is an increasing complexity of tasks, skills and knowledge acquisition”

Apprenticeship learning involves a learner, called the apprentice, learning content from a teacher who is an expert (Dennen & Burner, 2008). Apprenticeship is a teaching method used to teach learners how to solve problems, understand tasks and perform those tasks (Collins, Brown, & Newman, 1988). The main idea of apprenticeship learning is to allow learning to take place through coaching and facilitation. In contrast, in a traditional classroom, the teacher takes the directive role of teaching and provides limited opportunity for coaching and facilitation (Oriol, Tumulty, & Snyder, 2010).

Apprenticeship learning can be applied in mathematics by the teacher coaching and modelling how to solve the problems and providing ever more challenging tasks for the class to solve (Johnson & Fischbach, 1992). Learners can solve problems in groups, with the teacher acting as a coach until they become competent and require less assistance. The process involves observation, coaching and practice (Collins et al., 1988) until learners are able to find solutions on their own with less teacher involvement.

On RTS, an increasing complexity of tasks, skills and knowledge acquisition is supported. However, the coaching and modelling of how to solve the problems should be provided by the teacher. So, the teacher together with RTS are part of the apprenticeship learning process where the teacher becomes less involved with the learners and RTS as the competence of the learners improve.

2.5.5.17 Principle Fifteen: “Knowledge complexity is reflected...”

“Knowledge complexity is reflected in an emphasis on conceptual interrelatedness and interdisciplinary learning”

A concept is interrelated if it is influenced by other concepts. Interdisciplinary learning is an approach characterised by multidisciplinary knowledge across a theme (Ivanitskaya, Clark, Montgomery, & Primeau, 2002). The term interdisciplinary has been related to learning that requires forms of application and also to methods of more than one academic discipline to address an issue, question or a problem (Deneme & Ada, 2012). It is not just a combination of disciplines, but involves teachers blending those disciplines to connect content and activities for planning teaching and evaluating the learning process (You, 2017; Deneme & Ada, 2012; Jones, 2010). For example, this is evident when connecting the disciplines of mathematics, history and English (Deneme & Ada, 2012).
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Mathematics is enhanced when combined with other disciplines. Teachers can use other disciplines with mathematics to solve real-world problems. For example, learners can be presented with the metric system and the standard system in the United States (Furner et al., 2005). Teachers can then use map skills from social studies to create a scenario where students play tourists who have just arrived in the United States and need to solve problems converting between the two systems.

On RTS, conceptual interrelatedness is supported across the concepts of whole numbers, decimals, tables, percentages, fractions and money and operational concepts of addition, subtraction, multiplication and division. This together with the different levels of complexity supports knowledge complexity. Interdisciplinary learning is supported in relation to the discipline of finance. Other disciplines require the teacher to frame the problems presented in RTS in terms of those problems to solve real-world problems. In addition, RTS uses English language on its screens and promotes computer usage skills.

2.5.5.18 Principle Sixteen: “Collaborative and cooperative learning...”

“Collaborative and cooperative learning are favoured in order to expose the learner to alternative viewpoints”

Traditionally, learners listened passively to a teacher and memorised the lessons they received from the teacher (Kane & Harms, 2005). In contrast, collaborative learning is about allowing learners to work together in groups (Wenglinsky, 2001). Not only does it encourage team work, but it also focuses on the activities that promote learning processes during collaborative work (Dillenbourg, 1999). Learners become responsible for each other’s learning through the sharing of ideas and skills (Gokhale, 1995). Mathematics learning is often about asking questions, discussing problem solving skills and explaining one’s thinking (Fylnn, 2013). These types of interactive activities happen through collaboration.

Cooperative learning is also a form of collaborative learning. Cooperative learning allows learners to work together in smaller groups as a team to solve a problem or a task (Matthews, Cooper, Davidson, & Hawkes, 1995). The main idea is for learners to reach a goal (Johnson, Johnson, & Smith, 1984). Not only does it allow learners to share ideas, it also supports those learners with varied needs (Furner et al., 2005). In these groups, learners are actively involved, sharing ideas and helping each other to complete tasks (Zakaria, 2009). Furthermore, in a Constructivist classroom with cooperative and collaborative learning, learners are active, the teacher is a facilitator, learners are participating in group activities to develop their higher-order thinking skills and they also have responsibility for their own
learning (Matthews et al., 1995). In a mathematics class, the purpose of cooperative learning is to promote task-related interactions where learners can exchange ideas to achieve objectives (Leikin & Zaslavsky, 1999).

On RTS, learners can engage in different types of activities to successfully complete a task while working in groups as part of collaborative learning processes. In addition, RTS supports collaboration and cooperative learning through its group session facility which enables learners to work together on group activities. RTS provides a way for learners to engage with one another and communicate to solve the problems before submitting answers. In the group sessions with RTS, learners are exposed to different viewpoints for collaborative and cooperative learning and problem resolution. Since the software allows a time-out of each task, learners can collaborate and make sure that they work through the task before the time out. This creates active engagement between the learners as part of a Constructivist learning lesson.

2.5.5.19 Principle Seventeen: “Scaffolding is facilitated...”

“Scaffolding is facilitated to help students perform just beyond the limits of their ability”

Scaffolding is a teaching technique used to move learners progressively from their current level of knowledge to further levels of knowledge (Mishra, 2013). It involves a teacher providing successive stages of support and guidance, which are removed incrementally as a learner’s competencies develop and improved levels of knowledge are attained. In addition, the responsibility of learning is gradually passed onto the learner. Essentially, scaffolding is used to bridge learning gaps between what is known and what needs to be known. Scaffolding also aims to reduce frustration and demotivation when learners are faced with problems they currently do not understand or do not currently know how to solve.

For example, in a mathematics class, the first level of scaffolding could be to use artefacts such as wall displays, manipulatives and puzzles as introduction to a new concept (McMahon, 2000). At this level, the teacher’s motive is to encourage attention among the learners before going to more complex tasks. At the next level, there is direct interaction between the teacher and learners which involves showing, telling or explaining ideas that learners need to learn. This level gives learners the opportunity to be actively engaged with the mathematical ideas and problems to be solved (Anghileri, 2006). The final level could be where the teacher looks for development of the concepts in the learners through their critical thinking and understanding. This is also the stage were the teacher suggests learners come up with their own examples thus enabling learners to become aware of what they learned.
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On RTS, scaffolding is supported through the different levels of difficulty, the different types of problem value ranges such as values less than ten, less than twenty, and others, the choice to practice more often those problems where there is difficulty and the different feedback options. These features can help learners perform just beyond the limits of their current ability.

2.5.5.20 Principle Eighteen: “Assessment is authentic...”

“Assessment is authentic and interwoven with teaching”

Authentic assessment is the measurement of meaningful competencies, which often represent real-world problem solving (Frey & Schmitt, 2007). Authentic assessment involves criteria related to knowledge construction such as interpreting information, applying disciplined enquiry and demonstration and explanation through the oral or written form, that addresses problems or tasks beyond school or those encountered outside school (Scheurman & Newmann, 1998). For example, a teacher can assign a mathematics task to learners and would have to use real-world activities that are meaningful to the learners.

Svinicki (2004) explained how an assessment is authentic if it reflects the way the information or skills would be used in the real world; the assessment asks the student to “do” the subject, that is, to go through the procedures that are typical to the discipline under study. Furthermore, the assessment is done in situations as similar to the contexts in which the related skills are performed as possible and requires the student to demonstrate a wide range of skills that are related to a complex problem, including some that involve judgment. Finally, the assessment allows for feedback, practice and second chances to solve the problems being addressed (Svinicki, 2004).

Assessment can be said to be interwoven with teaching if the learners are provided with regular and frequent feedback during the learning process (Harlen & Johnson, 2014). This means that feedback is provided during the instructional process while learning is taking place in the classroom (Anandan, 2015). Traditionally, assessment is conducted at the end of lesson, which may provide less information about the learning process and how to improve it. Assessments on RTS are authentic by measuring meaningful mathematics competencies for the grade level and interwoven with teaching so that the learners work on the problems in RTS throughout the lesson while being guided and facilitated by the teacher. The learners can work individually or in groups on RTS throughout the lesson and RTS assesses their learning as they are taught the concepts. In addition, the teacher can conduct authentic assessment as
the lesson progresses, which provides important feedback for understanding where attention and teaching is required and when new concepts can be taught.

2.6 Chapter summary and conclusions

Chapter Two reviewed relevant literature relating to the research problem. The review discussed the following themes evident in the literature: General teaching challenges with disabled learners, mathematics teaching and learning relating to disabled and deaf learners, assistive technology and learning theories.

The chapter’s objectives were achieved by explaining the literature review process to demonstrate a rigorous literature review, uncovering key theories, models, frameworks, and phenomena in the domain, clarifying the contribution of the research, providing the answers to the Research Questions One and Two and achieving Sub-objective One. Thus, the main goal of the chapter has been accomplished, which was to synthesise previous studies in relation to the research problem.

In conclusion, it is evident that there are studies that show positive results, negative results and mixed results of assistive technology use for learners with special needs including deaf learners; so, assistive technology alone is not a guarantee of producing positive results. Thus, theories to guide the use of assistive technologies are necessary. The literature highlighted that Constructivism is conceptually applicable for learning environments that are mediated by technology. Thus, this study proceeds with Constructivism to guide the use of the selected assistive technology in the mathematics classroom for deaf learners and terms this combination Constructivist assistive technology.

In addition, it was apparent from the literature that teaching mathematics to deaf learners is difficult and research on this topic continues to be an imperative for improved learning. Furthermore, out of all the applications evaluated, RekenTest Software (RTS) was the most suitable as the study’s assistive technology because of its extensive design and potential to support most of principles of Constructivism in a classroom and RTS was designed to adapt itself to a specific student, based on that student's learning.

This chapter has value for academics because it demonstrates what is currently known about assistive technology, disabled learners and mathematics education and it demonstrates that further research is required. This chapter also has value for educational practice because the findings from previous studies provide guidance on the use of assistive technologies and expose the many factors that should be considered for achieving positive outcomes.
Chapter 2: Literature Review

The next chapter (Chapter Three) is the research methodology. Chapter Three describes, explains and justifies the study's research methodology. In addition, Chapter Three explains and details the procedures and design of the experiment and interviews.
Chapter 3: Research Methodology

3.1 Introduction
Chapter Two synthesised previous studies in relation to Constructivist assistive technology for the deaf in a mathematics classroom and presented eighteen principles of Constructivism and their applicability for the study’s deaf learners in a mathematics classroom using the selected assistive technology. Chapter Three continues by elaborating on the processes, planning, structuring and execution of the study.

The goal of Chapter Three is to define and justify the research methodology, which enables the study to answer Research Questions Three to Five. To this end, Chapter Three has the following chapter objectives; detailing and justifying the research strategy in relation to the research problem and objective, substantiating the sampling and data collection methods, developing the data collection instruments, detailing how bias is mitigated and research quality, rigor and ethics are ensured and explaining the data analysis methods.

Chapter Three continues by clarifying the research philosophy, the methodological choice and research strategy. Then, the sampling and data collection techniques and procedures are detailed. In addition, the development of the data collection instruments is explained and the data analysis methods are provided. Thereafter, procedures and measures for ensuring research quality and rigor are set out and research ethics details are presented. The final section in the chapter is the summary and conclusion section.

3.2 Research philosophy
Two common philosophies applicable to research projects are positivism and interpretivism (Saunders & Lewis, 2012). Positivism, with reference to epistemology, holds that knowledge about the world can be acquired objectively (Aliyu, Bello, Kasim, & Martin, 2014; Krauss, 2005). Thus, positivist research focuses on predicting outcomes of cause and effect amongst variables and testing proposed theories (Saunders & Lewis, 2012). In contrast, interpretivism considers that knowledge about the world is acquired subjectively since reality is uniquely experienced by each person and interpretivist research focuses on contextual complexity and human sense-making (Myers, 2013).

In contrast, pragmatism is a research philosophy that is not committed to any single system of reality and views reality as both independent of and dependent on the observer (Creswell, 2014). Adopting the philosophical position of pragmatism enables a researcher to choose research strategies, methods and techniques that best meet the needs of the research and are
best suited to answer the particular research questions, achieve the particular research objective and address the particular research problem (Creswell, 2014). Thus, this study adopted the philosophical position of pragmatism to best answer its research questions and address its research problem.

3.3 Methodological choice
Methodological choice follows from the adopted research philosophy (Saunders & Tosey, 2013). To answer Research Question Three the study had to collect and analyse quantitative data about the mathematics achievement of the learners and to answer Research Questions Four and Five, the study had to collect and analyse qualitative data from the teachers. So, the study’s methodological choice was mixed methods (Venkatesh, Brown, & Sullivan, 2016; Feilzer, 2010).

3.4 Research strategy

3.4.1 The mixed methods strategy
Subsequent to methodological choice is the study’s research strategy (Saunders & Tosey, 2013). To answer Research Question Three the study conducts an experiment comprising an experimental group of deaf learners who use the assistive technology, a control group of deaf learners who do not use the assistive technology and pre- and post-tests to measure the effect of the assistive technology. To answer the Research Questions Four and Five, the study pursues a survey research strategy comprising interviews with the teachers. The mixed methods strategy was sequential mixed methods where the researcher expanded on the findings from the experiment with the findings from the teacher interview survey (Creswell, 2014). The experiment was conducted first so that the teachers would have the experience of teaching with Constructivist assistive technology in a mathematics classroom for the deaf before the interviews were conducted.

3.4.2 The experiment
The study began its empirical research with a field experiment (Sekaran & Bougie, 2013). A field experiment enabled the researcher to investigate the effects of assistive technology on mathematics learning through an experimental group of deaf learners who used the assistive technology and a control group of deaf learners who did not use the assistive technology (Cook, Cook, Landrum, & Tankersley, 2008). The literature demonstrates that experiments have been used to test the effectiveness of assistive technology in various settings involving
learners with a variety of impairments and disabilities (Schmitt et al., 2012; Silió and Barbeta, 2010).

Essentially, a field experiment is an experiment conducted in the natural setting of the phenomenon of interest instead of the artificial setting of a laboratory (Sekaran & Bougie, 2013). Experiments are useful tools in educational research as well as in verifying educational improvements (Campbell & Stanley, 1963; Schanzenbach, 2012). An experiment can test the accuracy of a theory by determining if independent variables have any cause on a dependent variable (Lowhorn, 2007; Mohammed, 2014).

A field experiment is a research strategy that respects the natural setting of a classroom and controls how variables change over time (Salomon, 1991). Furthermore, an experiment is considered to be an appropriate research strategy for answers to educational questions where conditions and control groups can be manipulated (Charness, Gneezy, & Kuhn, 2012).

Importantly, experiments are useful in special education to understand the relationship between specified variables on instruction and the learning of learners with special needs (Charness, Gneezy, & Kuhn, 2012). The field experiment conducted was of the design where a pre-test was given to both the experimental group and the control group, then the experimental group was exposed to the treatment, which is the assistive technology, and thereafter, a post-test was given to both the experimental group and the control group (Sekaran & Bougie, 2013).

Thus, the field experiment enabled the researcher to study the effects of an independent variable, namely the Constructivist assistive technology involving RekenTest Software (RTS) on a dependent variable, namely the mathematics achievement of deaf learners. The selection of RTS as the assistive technology is substantiated in Section 2.5.4.2. The dependent variable, namely the mathematics achievement of deaf learners, was compared between an experimental group whose learners were taught with Constructivist assistive technology and a control group whose learners were taught with traditional methods and no assistive technology.

3.4.3 The interview survey

Surveys, including interview surveys, are popular methods for data collection about people to explain their experiences, behaviour and knowledge (Sekaran & Bougie, 2013). An interview survey enabled the researcher to investigate how the teachers’ teaching was affected by the Constructivist assistive technology and, according to those teachers, how their students’ learning was affected by the Constructivist assistive technology. The teachers involved were
regarded as experts in the selected teaching context since they have extensive and daily experience with the children’s teaching and learning.

In addition, advantages of face-to-face interviews include that they provide the opportunity to establish a rapport with participants and to motivate them, to clarify questions and pose additional questions, to observe non-verbal cues and obtain rich data (Sekaran & Bougie, 2013). Disadvantages of face-to-face interviews include that they take large amounts of time, may require expenditure for travelling, interviewees may have reservations and interviewer bias may be introduced (Sekaran & Bougie, 2013).

The researcher mitigated these disadvantages by setting aside enough time for the interviews and acquiring resources for travelling, establishing a rapport with the teachers, before, during and after the experiment and interviews, providing them with detailed information about the study in participant information sheets and verbally, and being aware of how questions were asked in the interviews so as not to distort the participants’ answers. The researcher undertook not to ask leading questions or questions loaded for preconceived or predetermined responses. Based on the advantages of face-to-face interviews, the interview survey proceeded with face-to-face interviews.

In addition, the interviews were semi-structured since semi-structured interviews provide a useful structure to focus the interviews while still allowing the researcher to improvise and pursue new lines of enquiry and the interviewee to add relevant insights as they occur (Myers, 2013). Furthermore, the interviews were conducted with a focus on elicitation and listening. Eliciting involves open-ended questions that are relatively indirect and give the interviewee the gentle opportunity to provide rich data. Listening involves concentrating, understanding the meaning behind the words and reflecting for confirmation and empathy.

3.5 Sampling

3.5.1 The experiment

The experiment involved deaf children in grade three and the subject of mathematics in a mostly rural region in Namibia, at a special school, as justified in Chapter One. Grade three is a grade where the children learn to build and understand foundational and basic mathematical concepts such as counting, which they require for subsequent mathematical concepts (Rudasill, Gallagher, & White, 2010) and grade three was perceived by the researcher and teachers at the school to be the lowest appropriate grade level for conducting the experiment so that the children would understand instructions and communication relating to the purposes of this study.
Nevertheless, the special school was a small school and the number of students in each grade was small with grade three having eight learners in 2018. Using small numbers for this type of research is not uncommon, for example, prior research using experiments to test assistive technology effects on learning have also involved small numbers of learners such as fourteen students (Hamadneh, Hamad, & Al-azzam, 2016), eighteen students (Zhang, Trussell, Gellogos and Asam, 2015), seven students (Fälth & Svensson, 2015), twenty students (Dündar & Akçayır, 2017) and eighteen subjects (Liu, Chiu, Hsieh, & Li, 2010). So, studies conducting experiments with small numbers of participants can still provide valuable insight and contribute to the body of knowledge.

For the experiment, random assignment was used to allocate the learners into either the experimental/treatment group or the control group. Randomized experiments are regarded as an effective method of assessing intervention between two groups in educational research (Chen & Green, 2010; Salomon, 1991; Seltman, 2012; Shadish et al., 2002). Furthermore, random assignment ensures that each learner has an equal chance of being assigned to either group (Sekaran & Bougie, 2013). The rationale for random assignment is to distribute any confounding variables among the groups equally (Sekaran & Bougie, 2013). Confounding variables could be variables such as gender, mathematics aptitude and health, that could influence the effect of the independent variable on the dependent variable, cause errors and biases and ruin the experiment.

Random assignment ensures that both groups are comparable and that all these variables are controlled (Chen & Green, 2013; Shadish, Cook, & Campbell, 2002). In addition, random assignment mitigates several threats to the internal validity of the study, which refers to the credibility of any cause and effect relationship evidenced in the study (Shadish et al., 2002). The threats mitigated are history, maturation, main testing, instrumentation, selection bias and statistical regression effects (Sekaran & Bougie, 2013). These threats are explained further in Section 3.8.3. To implement random assignment, the researcher used Microsoft Excel 2016’s random number generator to assign participants to either the control or the experimental group (Braucht & Reichardt, 1993). This was done by listing the names of the learners in alphabetical order in column A, then adding Microsoft Excel’s RAND() function in column B. Once random numbers were assigned to each row in column B, they were copied and pasted as constant values in the same column, so they would not change when working in the sheet. Then, the two columns were sorted in ascending order on column B. The first four learners in the sorted list were allocated to the initial control group and the last four learners to the initial experimental group.
Chapter 3: Research Methodology

3.5.2 The interview survey

Given the small size of the special school, there were only three teachers that were involved with the experiment. Thus, there were three interviewees. Such an approach to sampling is usual for qualitative research, where participants are purposefully selected to best answer the particular research questions (Creswell, 2014). Also, a great number of interviewees do not substitute for quality of interviews and there is often a trade-off between how much data is collected and how deeply that data can be analysed (Myers, 2013). So, while the opportunity for only three interviews existed, these provided extensive depth and data for answering the relevant research questions and providing convincing triangulation with the findings from the experiment (Yin, 2014).

Furthermore, in the literature there are several examples of previous assistive technology studies using relatively small numbers of participants with experimental designs and interviews, including a study that tested an assistive technology app for learners with dyslexia using only seven primary school students (Fälth & Svensson, 2015), a study that tested reading comprehension with tablet PC’s versus printed books using only twenty primary school students (Dündar & Akçayır, 2017) and a study that tested mobile phone usability with eighteen subjects (Liu et al., 2010). This provides evidence that studies comprising experiments and interviews with small numbers of participants can still provide valuable insight and contribute to the body of knowledge.

3.6 The experiment: Design, data collection and analysis

3.6.1 Data collection instruments

In order to answer Research Question Three, the mathematics achievement of participants required measurement before the experiment was conducted, a pre-test, and after the experiment was conducted, a post-test.

The data from the pre- and post-tests was primary data, which are data collected in the field during the course of an experiment (Boaduo, 2011; Gersten, Lloyd, & Baker, 1998; Kothari & Garg, 2014). The pre- and post-tests were mathematics achievement tests and the data type was quantitative. Also, the data were non-negative, which could subsequently be represented in ratios and/or percentages to describe how many correct answers participants provided in relation to the total number of questions in each pre- and post-test. The measurement scale of the data was considered to be ratio scale since there was an absolute zero point (Sekaran & Bougie, 2013). In addition, ratio scale measures differences between any two data points and the proportions of those differences.
The mathematics achievement of the learners was measured using mathematics achievement tests, which are used in most educational systems, are part of contemporary pedagogical practices, are generally accepted measures of learning (Bragg, 2012) and the learners in the study experienced achievement tests periodically at their school. The literature indicated that many technology in education studies using experimental designs used mathematics achievement tests to measure the effects of the technologies (Burns & Bozeman, 1981; Carr, 2012; Cheung & Slavin, 2013; Güzeller & Akın, 2012; Li & Ma, 2010; Petersen, McAuliffe, & Vermeulen, 2017; Zhang et al., 2015). For each item in each achievement test, a child who responded correctly was deemed to have demonstrated mathematics achievement of the corresponding concept (Bragg, 2012).

The experiment required two different pre-tests with corresponding post-tests since the experiment, as detailed in Section 3.6.2, is designed in two phases. Phase One involved the mathematics concepts of addition and subtraction only and Phase Two involved the mathematics concepts of multiplication and division only. The reason for conducting two phases is primarily to address the ethical issue of withholding benefits of the study from learners in the control group (Sekaran & Bougie, 2013) and to remove social threats to validity (Eagle & Barnes, 2009). Thus, the learners that were randomly assigned to the experimental group in Phase One became the control group in Phase Two and the learners randomly assigned to the control group in Phase One became the experimental group in Phase Two (Brown-Lopez & Alva, 2010; Huelar, 2012). The result was that all learners got to experience using the assistive technology during the study.

The pre-tests assessed the participants before implementing the treatment while the post-tests assessed the participants after implementing the treatment (Creswell, 2012). Pre-test-post-test designs have been widely used in research to compare groups and measure treatments in experiments (Dimitrov & Rumrill, 2003). In addition, pre-test-post-test designs have been extensively used in educational research (Campbell & Stanley, 1963) to measure cause and effect after implementing a treatment (Chandrakala, 2016).

For each phase of the experiment, the format of the questions in the post-test were the same as those in the corresponding pre-test and, importantly, the specific numbers were different. This ensured that the identical mathematical concepts were being tested, the learners required application of the necessary mathematics reasoning and the learners could not use memory and recall based on the pre-tests (Bragg, 2012). Each pre- and post-test comprised ten items only since the learners were in grade three and the mathematics conceptual scope for the
experiment was limited to addition, subtraction, multiplication and division in the grade three mathematics curriculum.

The pre- and post-tests were designed by the researcher in consultation with the mathematics teachers at the school where the data was collected. The primary objective for teacher consultation was to make sure that the test items accurately measured the required knowledge and skills of the learners, which promoted validity and reliability. Furthermore, the questions in the pre- and post-tests were aligned to the objectives and specifications of the curriculum standard for junior primary phase in Namibia (NIED, 2014) as well as the grade three mathematics textbooks. In addition, the questions in the pre- and post-tests were arranged according to their level of difficulty from easier questions to more difficult questions. The mark allocation for each question in each test was one for a correct answer and zero for an incorrect answer. For Phase One of the experiment or addition and subtraction, the Pre-test One and Post-test One questions are shown in Table 22 in Appendix E. For Phase Two of the experiment or multiplication and division, Pre-test Two and Post-test Two questions are shown in Table 23 in Appendix E.

3.6.2 Overall plan for the experiment

As indicated in Section 3.6.1, the study was conducted in two phases, namely Phase One and Phase Two. Phase One involved the mathematics concepts of addition and subtraction only and Phase Two involved the mathematics concepts of multiplication and division only. Importantly, both phases were conducted in the afternoons after normal school classes only. The study did not intervene, interfere or become involved with the learners in any way during normal school classes, except to have the teachers administer the Phase One and Phase Two pre-tests the week before the experiment was conducted. It was only in the afternoons after normal school classes that the learners participated in the study.

Both Phase One and Phase Two comprised a control and experimental group of learners, namely Phase One control group, Phase One experimental group, Phase Two control group and Phase Two experimental group. So, at the same time in the afternoons after normal school classes during both phases, learners randomly assigned to the control group were taught in a separate class to the learners randomly assigned to the experimental group. Also, the learners in the control group were taught the same concepts as the learners in the experimental group, except the control group that was taught using the traditional classroom principles and without assistive technology and the experimental group was taught using the Constructivist assistive technology.
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For both phases in the afternoons, the experimental group’s classroom had RTS installed on laptops as standalone installations and learners could access the program without needing internet access. The laptops were situated at each desk arranged in a U-shape facing the chalkboard as well as the teacher. The rationale of the U-Shape was to direct learners to the teacher during instructional activities, which not only facilitates the interaction between the teacher and the learners, but also improves participation, thinking and motivation (Ridling, 1994). Learners were arranged in groups at each laptop. The teacher’s desk was facing the learners while the researcher was seated at the back of the classroom. This was to ensure that the researcher did not distract the teaching process and could observe and make notes during the experiment as well as provide support for the software if there were any problems with the laptops and/or RTS.

Following are the high-level plans for both phases of the study, presented in Table 4 and Table 5, for the experimental group sessions that were conducted in the afternoons after normal school classes only. Again, the study did not intervene, interfere or become involved with the learners in any way during normal school classes, except to have the teachers administer the Phase One and Phase Two pre-tests the week before the experiment was conducted. Also, the learners in the control group were taught the same concepts as the learners in the experimental group, except the control group was taught using the traditional classroom principles and without assistive technology and the experimental group was taught using the Constructivist assistive technology.

**Table 4: Phase One experimental group: Addition and subtraction**

<table>
<thead>
<tr>
<th>Week &amp; Day</th>
<th>Start Time</th>
<th>End Time</th>
<th>Learning outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1, day 1</td>
<td>2:30pm</td>
<td>3:10pm</td>
<td>Learners should be able to:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Navigate RTS to configure, start, use, conduct and obtain feedback on RTS sessions.</td>
</tr>
<tr>
<td>Week 1, day 2</td>
<td>2:30pm</td>
<td>3:10pm</td>
<td>Learners should be able to:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Add a three-digit number below 500 with a two-digit number, with double carrying of tens and units.</td>
</tr>
<tr>
<td>Week 1, day 3</td>
<td>2:30pm</td>
<td>3:10pm</td>
<td>Learners should be able to:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Subtract a two-digit number from a three-digit number below 500, with double borrowing from hundreds and tens.</td>
</tr>
<tr>
<td>Week &amp; Day</td>
<td>Start Time</td>
<td>End Time</td>
<td>Learning outcomes</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>----------</td>
<td>-------------------</td>
</tr>
</tbody>
</table>
| Week 1, day 4 | 2:30pm | 3:10pm | Learners should be able to:  
  • Solve story problems involving addition of two two-digit numbers below 100 without carrying.  
  • Solve story problems involving subtraction of two two-digit numbers below 100 without borrowing. |
| Week 1, day 5 | 2:30pm | 3:10pm | Learners write Phase One Post-test One |

**Table 5: Phase Two experimental group: Multiplication and Division**

<table>
<thead>
<tr>
<th>Week &amp; Day</th>
<th>Start Time</th>
<th>End Time</th>
<th>Learning outcomes</th>
</tr>
</thead>
</table>
| Week 2, day 1 | 2:30pm | 3:10pm | Learners should be able to:  
  • Navigate RTS to configure, start, use, conduct and obtain feedback on RTS sessions. |
| Week 2, day 2 | 2:30pm | 3:10pm | Learners should be able to:  
  • Multiply a two-digit number by a one-digit number of 2, 3, 4, 5 or 10 with a product between 100 and 500, with single carrying of tens. |
| Week 2, day 3 | 2:30pm | 3:10pm | Learners should be able to:  
  • Divide a two-digit number up to 100 by a one-digit number or 10, with remainders. |
| Week 2, day 4 | 2:30pm | 3:10pm | Learners should be able to:  
  • Solve story problems involving multiplication of a two-digit number by a one-digit numbers of 2, 3, 4, 5 or 10 with a product between 100 and 500, with single carrying of tens.  
  • Solve story problems involving division of a two-digit number up to 100 by a one-digit number or 10, with remainders. |
| Week 2, day 5 | 2:30pm | 3:10pm | Learners write Phase Two Post-test Two |

3.6.3 Instructions for the teacher/s teaching the experimental groups

In addition to the mathematics content that was required to be covered during each day of the study as specified in Tables 4 and 5, the teacher/s in the experimental group were required to
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conduct the experiment classes in accordance with Constructivist principles. Before the study commenced, the researcher met with all the teachers involved, provided training on RTS and explained how each of the eighteen Constructivist principles detailed in Section 2.5.5, should be applied during the experimental group classes with RTS. These instructions are presented in Table 6.

Table 6: Instructions for the teacher/s in the experimental group in each phase

<table>
<thead>
<tr>
<th>No</th>
<th>Key principles of Constructivism (Murphy, 1997, pp. 11-13)</th>
<th>Instructions for the teacher/s in the experimental group in each phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>“Multiple perspectives and representations of concepts and content are presented and encouraged”.</td>
<td>Request learners to illustrate the mathematics problems in different representations together with RekenTest Software (RTS). For example, if RTS displays $7 + 3 = 10$, one learner may be asked to draw circles or lines on the chalkboard to represent the problem while another learner may be asked to represent the problem in words or in Namibian Signing Language.</td>
</tr>
<tr>
<td>2.</td>
<td>“Goals and objectives are derived by the student or in negotiation with the teacher or system”.</td>
<td>Set overall goals for each lesson. Then, allow the students to determine their own sub-goals through negotiation and involving RTS to achieve those overall goals. For example, learners can choose to practise addition of whole numbers with values less than ten only until this is mastered and, thereafter, values less than one hundred and so on until the required level is mastered.</td>
</tr>
<tr>
<td>3.</td>
<td>“Teachers serve in the role of guides, monitors, coaches, tutors and facilitators”.</td>
<td>Act as a facilitator, tutor and guide assisting the learners to grasp the concepts by using RTS. For example, learners are put into groups and each group is encouraged to work together to solve problems. While they reason and discuss the problems in their groups, you, the teacher, walks around to the groups to observe and see how learners are solving the problems. If learners are struggling to get the correct answer on RTS, you ask questions, provide hints and suggest supporting exercises on RTS rather than giving the correct answers so that learners can solve the problems on their own.</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>No</th>
<th>Key principles of Constructivism (Murphy, 1997, pp. 11-13)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>4.</td>
<td>“Activities, opportunities, tools and environments are provided to encourage metacognition, self-analysis, self-regulation, self-reflection &amp; self-awareness”.</td>
<td>Direct the learners to RTS and its assessment features so that learners can practise and think about their own learning as they proceed through the problems. For example, once learners have negotiated their objectives, you, the teacher, direct them to RTS and then guide them on how to use RTS to achieve those goals, which includes self-assessment on RTS.</td>
</tr>
<tr>
<td>5.</td>
<td>“The student plays a central role in mediating and controlling learning”.</td>
<td>Allow the learners to choose what content to practice, at what level and to what proficiency on RTS. For example, learners may choose to work on simple tasks, complex tasks or a combination of the two. It encourages them to make their own decisions about and control their learning.</td>
</tr>
<tr>
<td>6.</td>
<td>“Learning situations, environments, skills, content and tasks are relevant, realistic, authentic and represent the natural complexities of the 'real world'”.</td>
<td>Frame learning in terms of real-world situations and scenarios as often as possible. For example, the money function in RTS helps learners to understand that addition or subtraction can be applied outside of the school if one has to go and buy something at the tuckshop. In this way, learners are provided with the opportunity to practise realistic and authentic real-world tasks. In addition, you, the teacher, may give a class activity whereby learners have to come up with their own real-world problems corresponding to the problems provided by RTS. During these activities, learners are given the opportunity to understand the concepts outside of their school environment and apply it in their daily lives as part of relevant, realistic and authentic assessment.</td>
</tr>
</tbody>
</table>
# Key principles of Constructivism (Murphy, 1997, pp. 11-13)

<table>
<thead>
<tr>
<th>No</th>
<th>Instructions for the teacher/s in the experimental group in each phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.</td>
<td>“Primary sources of data are used in order to ensure authenticity and real-world complexity”. Use primary sources of data during the sessions to facilitate learning. For example, you, the teacher, can use coins as a primary source of data and the learners can work with the coins adding and subtracting accordingly to replicate real-world purchasing or shopping scenarios. You may also use primary sources of data such as newspaper and magazine articles describing simple mathematical issues that the learners can understand. Your role is to ensure that the sources of data are aligned with the current concept studied so that learners are aware of the authenticity of the tasks and how it can be applied in real-world settings.</td>
</tr>
<tr>
<td>8.</td>
<td>“Knowledge construction and not reproduction is emphasized”. Guide the learners to use the knowledge that they already have to develop new knowledge. For example, you, the teacher, guide the learners to check their answers on RTS after every task completed. If their answers are wrong, you allow them to discuss it within their groups and even with you to understand where they made the errors and how to construct the required knowledge from their current knowledge base. The process is to allow learners to construct knowledge through their activities on RTS and engagement within their groups and you.</td>
</tr>
<tr>
<td>9.</td>
<td>“Construction takes place in individual contexts and through social negotiation, collaboration and experience”. Arrange the learners in groups and require them to learn by collaborating and discussing the problems in their groups. For example, learners can be arranged in small groups with each computer having RTS installed. As part of collaborative learning, learners work together in groups on the problems provided by the software, they negotiate the questions by sharing their own ideas and opinions and share their experiences involving similar problems. The learners work collaboratively to analyse and reflect on what they have learned before as part of social negotiation to achieve their goal, which is submitting the correct answer.</td>
</tr>
<tr>
<td>No</td>
<td>Key principles of Constructivism (Murphy, 1997, pp. 11-13)</td>
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<tr>
<td>----</td>
<td>----------------------------------------------------------</td>
</tr>
<tr>
<td>10.</td>
<td>“The learner's previous knowledge constructions, beliefs and attitudes are considered in the knowledge construction process”.</td>
</tr>
<tr>
<td>11.</td>
<td>“Problem-solving, higher-order thinking skills and deep understanding are emphasized”.</td>
</tr>
<tr>
<td>12.</td>
<td>“Errors provide the opportunity for insight into students’ previous knowledge constructions”.</td>
</tr>
<tr>
<td>No</td>
<td>Key principles of Constructivism (Murphy, 1997, pp. 11-13)</td>
</tr>
<tr>
<td>----</td>
<td>----------------------------------------------------------</td>
</tr>
<tr>
<td>13</td>
<td>“Exploration is a favoured approach in order to encourage students to seek knowledge independently and to manage the pursuit of their goals”</td>
</tr>
<tr>
<td>14</td>
<td>“Learners are provided with the opportunity for apprenticeship learning in which there is an increasing complexity of tasks, skills and knowledge acquisition”</td>
</tr>
<tr>
<td>No</td>
<td>Key principles of Constructivism (Murphy, 1997, pp. 11-13)</td>
</tr>
<tr>
<td>----</td>
<td>----------------------------------------------------------</td>
</tr>
<tr>
<td>15.</td>
<td>“Knowledge complexity is reflected in an emphasis on conceptual interrelatedness and interdisciplinary learning”.</td>
</tr>
<tr>
<td>16.</td>
<td>“Collaborative and cooperative learning are favoured in order to expose the learner to alternative viewpoints”.</td>
</tr>
<tr>
<td>17.</td>
<td>“Scaffolding is facilitated to help students perform just beyond the limits of their ability”.</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>No</th>
<th>Key principles of Constructivism (Murphy, 1997, pp. 11-13)</th>
<th>Instructions for the teacher/s in the experimental group in each phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.</td>
<td>“Assessment is authentic and interwoven with teaching”.</td>
<td>Assess the learners continually through the lesson and assess meaningful mathematics competencies. For example, learners can work on the problems in RTS throughout the lesson while being guided and facilitated by the teacher. The learners can work individually or in groups on RTS throughout the lesson and RTS assesses their learning as they are taught the concepts. In addition, the teacher is provided with authentic assessment interwoven with teaching as the lesson progresses, which provides important feedback for understanding where attention and teaching is required and when new concepts can be taught.</td>
</tr>
</tbody>
</table>

3.6.4 Data analysis: Principles and process

The pre- and post-tests were mathematics achievement tests with quantitative marks assigned during their assessment. This data were non-negative, which could subsequently be represented in ratios and/or percentages to describe how many correct answers participants provided in relation to the total number of questions in each pre- and post-test. Such data was suitable for statistical analysis. Useful statistics used in comparable studies include means and frequencies of correct answers for the groups and cross-tabulations between questions (Bragg, 2012), standard deviations (Hamadneh, Hamad, & Al-azzam, 2016), percentages and t-tests to measure statistically significant differences between experimental and control groups (Zhang, Trussell, Gellogos & Asam, 2015).

Accordingly, in the study, to answer Research Question Three, several t-tests were done. The first were independent t-tests done on the pre-tests only to determine if there were any significant difference between the experimental and control groups at the start, and to check whether any group began with a significant advantage over the other. A similar independent samples t-test was done on the post-tests only, which did not measure the effect of the Constructivist assistive technology on the mathematics achievement relative to the learner’s starting achievement, instead it only tested for a significant difference at the end, which may or may not have been due to the constructivist assistive technology. In addition, paired samples t-tests were done for each group between their pre- and post-test scores for each phase to determine if there was a statistically significant change over the time of the study.
Again, these did not measure the effect of the Constructivist assistive technology on the mathematics achievement between the groups, only a statistically significant change over the time of the study. To test the effect of the Constructivist assistive technology on the mathematics achievement of the learners since the start and between the experimental and control groups, an independent t-test was conducted on the difference between the pre- and corresponding post-test scores.

T-tests have been used in educational researches involving small sample sizes (De Winter, 2013). These measures assist to determine whether the intervention of the assistive technology was effective or not (Cook et al., 2008). The Statistical Package for the Social Sciences (SPSS) was used to process and analyse the data.

### 3.7 The interview survey: Data collection and analysis

#### 3.7.1 Data collection instrument

While quantitative data can be counted and displayed in values and numbers, qualitative data cannot and is often represented in the form of words generated from interviews (Sekaran & Bougie, 2013). Interviews collect primary qualitative data, which are often voice recorded during the interviews, transcribed into visual words and then the transcripts are analysed using appropriate qualitative data analysis techniques.

In preparation for any interview, it is useful to develop an interview guide (Myers, 2013). Since the purpose of the study’s interview survey was to answer Research Questions Four and Five, these two research questions were the point of departure for all the initial questions in the semi-structured interview guide. Importantly, the initial interview questions, presented in Table 7, covered all the aspects in the research questions, remain objective and did not lead the interviewees.

<table>
<thead>
<tr>
<th>Applicable Research Question</th>
<th>Initial Questions for the Interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Question 4:</td>
<td>How was your overall experience teaching with the Constructivist assistive technology?</td>
</tr>
<tr>
<td>According to the teachers, who are regarded as experts in</td>
<td>Which Constructivist principles do you think were the most important for your teaching, and why?</td>
</tr>
</tbody>
</table>
### Applicable Research Question

<table>
<thead>
<tr>
<th>Research Question 5: According to the teachers, who are regarded as experts in the selected teaching context, how were their students’ learning affected by the Constructivist assistive technology?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall, do you think the RekenTest Software (RTS) is suitable for teaching a Constructivist classroom, and why?</td>
</tr>
<tr>
<td>Do you think that RTS alone or Constructivist principles alone would be better than the combined RTS and Constructivist principles for teaching, and why?</td>
</tr>
<tr>
<td>Which Constructivist principles were easy and difficult to implement as part of your teaching with RTS in the classroom, and why?</td>
</tr>
<tr>
<td>What changes to RTS could you recommend for a better alignment with all the Constructivist principles for teaching?</td>
</tr>
<tr>
<td>What changed in your teaching due to the Constructivist assistive technology compared to your usual classrooms without it?</td>
</tr>
<tr>
<td>How was teaching easy or difficult with the Constructivist assistive technology, and why?</td>
</tr>
<tr>
<td>What aspects of the Constructivist assistive technology were most and least beneficial for your teaching, and why?</td>
</tr>
<tr>
<td>What would you like to change with the Constructivist assistive technology to benefit your teaching, and why?</td>
</tr>
</tbody>
</table>

### Initial Questions for the Interviews

<table>
<thead>
<tr>
<th>the selected teaching context, how was their teaching affected by the Constructivist assistive technology?</th>
</tr>
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<tbody>
<tr>
<td>Overall, do you think the RekenTest Software (RTS) is suitable for teaching a Constructivist classroom, and why?</td>
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<th>Applicable Research Question</th>
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<tbody>
<tr>
<td></td>
<td>What changed in the students' learning due to the Constructivist assistive technology compared to their usual classrooms without it?</td>
</tr>
<tr>
<td></td>
<td>How was learning easy or difficult with the Constructivist assistive technology, and why?</td>
</tr>
<tr>
<td></td>
<td>What aspects of the Constructivist assistive technology were most and least beneficial for the students' learning, and why?</td>
</tr>
<tr>
<td></td>
<td>What would you like to change with the Constructivist assistive technology to benefit the students' learning, and why?</td>
</tr>
</tbody>
</table>

In addition to the interview questions, the interview process aspects of preparation, introduction, conversation and conclusion require attention and care (Myers, 2013). Preparation includes gaining a fair understanding of the interviewees and the school that they work for before the interviews, pre-testing the questions for appropriateness and dressing suitably for the interviews. The introduction aspect involves the researcher introducing herself to the interviewees to build rapport and trust, which often includes small talk and the researcher explaining the purpose of the interviews clearly, enthusiastically and convincingly to establish credibility. The conversation aspects refer to asking the open-ended questions to elicit rich data, listening carefully and being respectful and sensitive so that new questions can be appropriately asked at the right times. The conclusion aspect requires that the interviewer thank the interviewees for their time and involvement and ask if they have any questions for the researcher.

3.7.2 Data analysis: Principles and process

The qualitative data analysis proceeded with bottom-up analysis (Myers, 2013). This means that relevant concepts and their interrelationships emerge during the data analysis instead of having a set of initial predetermined concepts and their interrelationships, and testing those with the data. In addition, given the small number of interviewees, the study aimed for depth of analysis (Myers, 2013). The general process for the interviews was to voice record them at the same time, then transcribed them into visual words, on word processor software, and thereafter, to analyse the transcripts using appropriate qualitative data analysis techniques and qualitative data analysis software, namely Atlas.ti.
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The data analysis proceeded with qualitative data coding (Myers, 2013). Qualitative data coding is an analytic process to reduce and rearrange huge volumes of words into integrated theories so that meaningful conclusions can be drawn from the data (Sekaran & Bougie, 2013). Qualitative data codes are essentially labels comprising one or many concise terms to describe various units of text, which can be words, sentences or paragraphs. Codes can also be applied to recognisable themes in the text.

To begin, initial codes were assigned throughout the texts in the transcripts, then, focussed coding was conducted, which involved selecting the most frequent or prominent initial codes to arrange, organise and integrate the data. Thereafter, theoretical coding was performed to develop categories from the focussed codes, which are more abstract codes for groups of closely related focused codes. Theoretical coding also specified relationships between the developed categories to form a coherent and integrated explanatory theory so that the researcher could draw meaningful conclusions from the data (Corbin & Strauss, 2008; Urquhart, Lehmann, & Myers, 2010). Importantly, memos were critical throughout the data analysis steps since they provided a record and enabled the development of the researcher’s analytical insights from the data (Corbin & Strauss, 2008). Memos were typically informal and spontaneous analytical notes written by the researcher to show what the researcher understood about the data.

3.8 Research quality and rigor-procedures and measures

3.8.1 Bias-types and mitigation: The experiment

Bias in research occurs when a systematic error is introduced in sampling or testing by selecting or encouraging one outcome or answer over another (Rivera, Mason, Jabeen, & Johnson, 2015). Bias can occur at ay phase of a study including design, sampling, data collection and analysis. However, to prevent bias in research, a proper design and implementation should be well defined and implemented in a study.

Specifically, bias in research can be present when characteristics of respondents such as ethnicity, language, gender, race and religions are distorted in a study (Meanwhile, Gay, Mills, & Airasian, 2009). This can be termed selection bias, which occurs during sampling of participants (Pai, 2011; Pannucci & Wilkins, 2010). This bias occurs when criteria to select the different groups is not the same. However, random assignment mitigates this bias by spreading all contaminating variables across all groups (Sekaran & Bougie, 2013).

Another bias in experimental designs is experimenter bias which is caused when a researcher purposefully acts to influence the results to portray a certain outcome (Muijs, 2011; Lodico,
Chapter 3: Research Methodology

Spaulding, & Voegtle, 2010). This bias is mitigated by the researcher not being actively involved in the pre- and post-test administration or teaching functions in either of the groups. The researcher only provided RTS software support and interacted with the teachers when necessary for the study.

3.8.2 Reliability: Quantitative experiment
An important criterion in quantitative research is reliability (Golafshani, 2003). For research to be reliable, it must employ data collection methods and analysis that provide consistent findings. For instance, measures used should produce similar results if used in other studies (Saunders & Lewis, 2012). The reliability of the experiment’s pre- and post-tests was measured using Cohen’s Kappa, which is a measure of rating agreement that corrects for chance agreement (Antia, Jones, Luckner, Kreimeyer, & Reed, 2011). Cohen’s Kappa requires two raters, who were deliberately chosen and qualified teachers at the school, to rate each question on the pre- and post-tests with a "Yes, the question is appropriate" or "No, the question is not appropriate". The details of the study’s reliability or Cohen’s Kappa of the experiment’s pre- and post-tests are provided in Section 3.9.

3.8.3 Validity: Quantitative experiment
Validity is about measuring the concepts that are intended to be measured (Sekaran & Bougie, 2013). Generally, field experiments are regarded to have better external validity or generalisability to other similar contexts and people than laboratory experiments since field experiments reflect real-world settings (Sekaran & Bougie, 2013). Any uncontrolled variables affecting the performance on a dependent variable in an experiment are a threat to research validity (Gay et al., 2009). An experiment is valid if the results obtained are due only to the manipulated independent variable/s. To promote validity in the study’s experiment, the researcher developed the pre- and post-test questions in alignment with the objectives and specifications of the curriculum standard for the junior primary phase in Namibia (NIED, 2014) as well as the grade three mathematics textbooks; then they were reviewed by the study’s supervisor and thereafter examined by the experienced teachers at the school, who also checked the wording of the questions and the time required to answer the questions on the tests. In addition, the teachers at the school expressed their opinions on the appropriateness of each item. All recommendations were acknowledged and the affected items were changed accordingly. Such expert reviews promote face and content validity (Nizoloman, 2013). Face validity refers to whether experts think that the instrument measures what it indicates that it measures and content validity
refers to whether the instrument comprises an adequate and representative set of questions to measure the intended concepts.

Often, in experiments there is a trade-off between internal and external validity (Sekaran & Bougie, 2013). Internal validity is about establishing cause-and-effect relationships and external validity is about establishing whether any discovered cause-and-effect relationships apply equally to other settings and scenarios. This study aimed for internal validity to address its research problem. Further studies could then focus on establishing external validity or generalisability to broader contexts.

In addition, random assignment ensured that both the experimental and control groups in the study were comparable and that confounding variables were spread across both groups. Random assignment mitigates several threats to the internal validity of the study, which refers to the credibility of any cause-and-effect relationship evidenced in the study. The threats mitigated are history, maturation, main testing, instrumentation, selection bias and statistical regression (Sekaran & Bougie, 2013). History effects are those unanticipated external happenings that could impact on the cause-and-effect relationship being measured in the study. Maturation effects relate to the effect of the passage of time on the participants. Main testing effects relate to the pre-tests affecting how the participants answer the post-tests. Instrumentation effects refer to changes in the measuring instrument between the pre- and post-tests. Selection bias effects are due to significant differences between the participants in the experimental and control groups. Statistical regression effects occur when the participants in the experimental group have extreme scores on the dependent variable at the start of the experiment (Sekaran & Bougie, 2013).

3.8.4 Bias-types and mitigation: Qualitative interview survey

A number of biases can occur during interview surveys (Choi & Pak, 2005). These include interviewer bias where the interviewer may not be objective and may gather selective data and question biases where questions may be ambiguous or leading. To mitigate these biases, the study’s supervisor reviewed the interview questions for alignment to the study’s research problem and objective (Chenail, 2009). Thereafter, as indicated in section 3.9, the interview guide was pre-tested, which provided the opportunity to test the interview administration, ask for feedback on difficult questions and ambiguities, confirm the time taken to complete the interview, remove any unnecessary questions, assess the range of responses to the questions, check that replies can be interpreted in relation to the study’s purpose and refine any problematic questions (Chenail, 2009).
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3.8.5 Trustworthiness: Qualitative interview survey

The assessment of qualitative research quality is different from that of quantitative research which involves assessing reliability and validity. The assessment of qualitative research quality involves the idea of trustworthiness, which has four criteria, namely transferability, credibility, confirmability and dependability (Shenton, 2004). Transferability in qualitative research can be likened to external validity or generalisability in quantitative research, credibility in qualitative research can be likened to internal validity in quantitative research, confirmability in qualitative research can be likened to objectivity in quantitative research and dependability in qualitative research can be likened to reliability in qualitative research (Shenton, 2004).

The study supported transferability by providing rich detail about the context of the fieldwork, interviewee responses and resulting analyses to enable the reader to decide whether the findings can be justifiably applied to another related context. Credibility relates to whether a true depiction of the study’s phenomena is presented and was provided by justifying the study in terms of prior research, adopting well-established research methods, understanding the culture of the school and providing rich descriptions of the data (Shenton, 2004). Confirmability refers to demonstrating that findings have emerged from the data and not the researcher’s own personal preferences, biases or preconceived ideas and was ensured by exposing the rigorous qualitative analysis processes and procedures and corresponding findings (Shenton, 2004). Dependability was maintained by providing complete, detailed and cohesive accounts of the research from problem inception to final conclusions, including interview voice data, transcripts and data analyses, so that future researchers can conduct replication studies (Shenton, 2004).

3.9 Cohen’s Kappa and the interview guide pre-test

The experiment’s pre- and post-tests were reviewed and evaluated by two teachers, experts in the context, at the school who expressed their opinions on the appropriateness of each question in each pre- and post-test. All recommendations were acknowledged and the affected items were changed accordingly.

As indicated in section 3.8.2, the reliability of the pre- and post-tests were measured using Cohen’s Kappa. On all the tests, both raters were in complete agreement on what was appropriate or not appropriate, and how to change the items that were not appropriate. Only on the addition and subtraction pre-test and corresponding post-test, both raters agreed that
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four items should be changed in format only, from horizontal format to vertical. There were no problems with any of the numbers or calculations on any of the tests.

The interview guide was pre-tested with a teacher other than one of the interviewees, selected by convenience sampling. Convenience sampling is appropriate for pretesting an interview guide, but not for analysing any data (Sekaran & Bougie, 2013). The purpose was to expose any ambiguities, grammatical problems or other weaknesses before the interviews commenced so that refinements could be made. Notably, a pre-test is not a pilot study since a pilot study is a small-scale version of the full study and a pilot study is applied in the same way as the full study, which includes the data analysis.

In addition, during the time before the experiment, training was conducted for two mathematics teachers as well as the principal to ensure that they familiarise themselves with the software and the study’s empirical work. Also, the researcher made sure that the computers and internet facilities are in place and ready for the experiment.

3.10 Research ethics

Creswell (2014) emphasises that obtaining ethics clearance is required in research before undertaking any study. Gaining access to conduct a study not only implies getting permission, but also a commitment from the researcher to conduct research in an ethical way (Creswell, 2014). Data collection was done only after permission was received from the Ministry of Education in Namibia and the applicable Regional Directorate of Education in Namibia. After being granted permission from these two entities, permission was sought from the principal of the special school in the region in Namibia. In addition, ethical clearance was required from the Unisa School of Computing before any data could be collected. The ethical clearance is in line with the Unisa research ethics policy that ensures the rights of participants are protected in the study (UNISA, 2016). Ethical clearance was obtained from the Unisa School of Computing before any data was collected; the ethical clearance certificate numbered 061/LKSA/2018/CSET_SOC is provided in Appendix C.

In addition, since the grade three children participating in the study were below the age of eighteen, permission from each child’s parents was required before their child could participate. In the request for permission to each child’s parents, the researcher provided a formal letter that included the purpose of the study, the time frame of the study, time required from the participants, the benefits to participants, any potential harm that could be experienced and the participants’ rights that include that participation is voluntary, their identities will not be disclosed in publications and that they may withdraw at any time from
Chapter 3: Research Methodology

the study without reason (Creswell, 2014; Lodico et al., 2010). Following permission from
the participants to partake in the study, it was the responsibility of the researcher to ensure
confidentiality and anonymity of the participants in the study. The children’s parents were
also required to sign informed consent forms. Informed consent is about informing the
research participants to enter the research of their own free will and that they understand the
nature of the study (Gay et al., 2009). According to Lodico et al. (2010), informed consent is
the process of giving information to the participants in the study about the risks involved in
the study and the right to withdraw from the study. Furthermore, for the interview survey part
of the study, each interviewee, too, had to provide informed consent before any interview was
conducted.

3.11 Chapter summary and conclusion

Chapter Three explained the study’s research methodology, which was guided by the study’s
research problem and research objective to provide scientific evidence of the effects of
Constructivist assistive technology for the deaf at a rural Namibian special primary school.
Chapter Three achieved the following specified objectives, detailing and justifying the
research strategy in relation to the study’s research problem and objective, substantiating the
sampling and data collection methods, developing the data collection instruments, detailing
how bias is mitigated and how research quality, rigor and ethics were ensured and explaining
the data analysis methods. Thus, Chapter Three achieved its goal, which was to define and
justify the study’s research methodology, which enabled the study to answer Research
Questions Three to Five.

In conclusion, the research philosophy, methodological choice and research strategy were
considered consistent and appropriate for answering the study’s Research Questions Three to
Five. In addition, the development processes for the research instruments were provided and
justified, which provides direction for other researchers in similar domains of research.
This chapter has value for academics since it presents an appropriate methodology for
exposing the effects of Constructivist assistive technology and it presents justifications for
each methodological choice to support the claim of rigor and relevance. This chapter also has
value for teaching practice by detailing an acceptable way of gathering evidence to inform the
inclusion of Constructivist assistive technology in classrooms. The next chapter is Chapter
Four and it provides the presentation, analysis and discussion of the research data.
Chapter 4: Presentation, Analysis and Discussion of the Data

4.1 Introduction

Chapter Three defined and justified the study’s research methodology and essentially the plan for how the study’s empirical work was to be carried out. Chapter Four discusses how that plan was actually carried out and the results of carrying out that plan.

The goal of Chapter Four is to present, analyse and discuss the data gathered for answering Research Questions Three to Five and achieving Sub-objective Two. To achieve this goal, Chapter Four has the objectives of describing the participants, reporting on the implementation of the research methods, analysing the data and discussing the findings. Chapter Four continues by first detailing the experiment and then the interviews. Thereafter, the member checking is explained and the chapter summary and conclusions are provided.

4.2. The experiment

4.2.1 Implementation of the experiment

The experiment was conducted over two weeks at the special school in the afternoons after normal school classes only and it began on Friday 09 November 2018 and was completed on Thursday 22 November 2018. Two classrooms were used for the study, one for the experimental group and one for the control group. The study followed the high-level plans for both phases of the study as detailed in Section 3.6.2 and presented again in Table 8 and Table 9.

Table 8: Phase One experimental group: Addition and subtraction

<table>
<thead>
<tr>
<th>Week &amp; Day</th>
<th>Start Time</th>
<th>End Time</th>
<th>Learning outcomes</th>
</tr>
</thead>
</table>
| Week 1, day 1: Friday 09 November 2018 | 2:30pm | 3:10pm | Learners should be able to:  
  • Navigate RTS to configure, start, use, conduct and obtain feedback on RTS sessions. |
| Week 1, day 2: Monday 12 November 2018 | 2:30pm | 3:10pm | Learners should be able to:  
  • Add a three-digit number below 500 with a two-digit number, with double carrying of tens and units. |
### Table 9: Phase Two experimental group: Multiplication and Division

<table>
<thead>
<tr>
<th>Week &amp; Day</th>
<th>Start Time</th>
<th>End Time</th>
<th>Learning outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1, day 3: Tuesday 13 November 2018</td>
<td>2:30pm</td>
<td>3:10pm</td>
<td>Learners should be able to:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Subtract a two-digit number from a three-digit number below 500, with double borrowing from hundreds and tens.</td>
</tr>
<tr>
<td>Week 1, day 4: Wednesday 14 November 2018</td>
<td>2:30pm</td>
<td>3:10pm</td>
<td>Learners should be able to:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Solve story problems involving addition of two two-digit numbers below 100 without carrying.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Solve story problems involving subtraction of two two-digit numbers below 100 without borrowing.</td>
</tr>
<tr>
<td>Week 1, day 5: Thursday 15 November 2018</td>
<td>2:30pm</td>
<td>3:10pm</td>
<td>Learners wrote Phase One Post-test One</td>
</tr>
<tr>
<td>Week 2, day 1: Friday 16 November 2018</td>
<td>2:30pm</td>
<td>3:10pm</td>
<td>Learners should be able to:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Navigate RTS to configure, start, use, conduct and obtain feedback on RTS sessions.</td>
</tr>
<tr>
<td>Week 2, day 2: Monday 19 November 2018</td>
<td>2:30pm</td>
<td>3:10pm</td>
<td>Learners should be able to:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Multiply a two-digit number by a one-digit number of 2, 3, 4, 5 or 10 with a product between 100 and 500, with single carrying of tens.</td>
</tr>
<tr>
<td>Week 2, day 3: Tuesday 20 November 2018</td>
<td>2:30pm</td>
<td>3:10pm</td>
<td>Learners should be able to:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Divide a two-digit number up to 100 by a one-digit number or 10, with remainders.</td>
</tr>
</tbody>
</table>
### Week & Day

<table>
<thead>
<tr>
<th>Start Time</th>
<th>End Time</th>
<th>Learning outcomes</th>
</tr>
</thead>
</table>
| **Week 2, day 4:** Wednesday, 21 November 2018 | 2:30pm | 3:10pm | Learners should be able to:  
- Solve story problems involving multiplication of a two-digit number by a one-digit numbers of 2, 3, 4, 5 or 10 with a product between 100 and 500, with single carrying of tens.  
- Solve story problems involving division of a two-digit number up to 100 by a one-digit number or 10, with remainders.  
| **Week 2, day 5:** Thursday, 22 November 2018 | 2:30pm | 3:10pm | Learners wrote Phase Two Post-test Two |

As per Section 3.5.1, the experiment involved deaf learners in grade three and the subject of mathematics. At the special school the learners were randomly assigned to either an experimental or control group before the experiment began and they were assigned the codes Learner01 to Learner08. The experimental group had four learners and the control group had four learners. The control group was taught in a separate class to the learners in the experimental group and the learners in the control group were taught the same concepts as the learners in the experimental group, except that the control group was taught using the traditional classroom principles and without assistive technology, and the experimental group was taught using the Constructivist assistive technology.

For both phases, in the afternoons, the experimental group’s classroom had RTS installed on laptops as standalone installations and learners could access the program without needing internet access. The laptops were situated at each desk arranged in a U-shape facing the chalkboard as well as the teacher. Learners were arranged in groups at each laptop. The teacher’s desk was facing the learners while the researcher was seated at the back of the classroom. This was to ensure that the researcher did not distract the teaching process and could observe and make notes during the experiment as well as provide support for the software if there were any problems with the laptops and/or RTS.

In addition, three teachers who taught at the special school were directly involved in the study and they were assigned the codes MT01 to MT03 (MT refers to Mathematics Teacher). The teachers were selected because they were the most familiar with teaching the grade threes in
Chapter 4: Presentation, Analysis and Discussion of the Data

the school, given the size of the school and the number of teachers at the school. MT01 was a grade three mathematics teacher with good hearing, MT02 was a grade one mathematics teacher who was deaf and MT03 was a grade two mathematics teacher with good hearing, and all three teachers were proficient in Namibian Sign Language and could teach grade three mathematics. While only two teachers were required to teach the experimental and control group classes, MT02 was included to gain further insight from a deaf teacher’s perspective. The deaf teacher did not teach during the study, but only observed during both experimental classes during each phase and, on a few occasions, observed the control classes. Table 10 and 11 show the allocation of the learners and teachers to the experimental and control groups.

Table 10: Phase One-Addition and Subtraction: Allocation of the learners and teachers to the experimental and control groups

<table>
<thead>
<tr>
<th>Groups</th>
<th>Mathematics Teachers</th>
<th>Learners in Grade Three</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
<td>MT01, MT02</td>
<td>Learner01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Learner03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Learner04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Learner06</td>
</tr>
<tr>
<td>Control group</td>
<td>MT03</td>
<td>Learner02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Learner05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Learner07</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Learner08</td>
</tr>
</tbody>
</table>

Table 11: Phase Two-Multiplication and Division: Allocation of the learners and teachers to the experimental and control groups

<table>
<thead>
<tr>
<th>Groups</th>
<th>Mathematics Teachers</th>
<th>Learners in Grade Three</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
<td>MT02, MT03</td>
<td>Learner02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Learner05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Learner07</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Learner08</td>
</tr>
<tr>
<td>Control group</td>
<td>MT01</td>
<td>Learner01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Learner03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Learner04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Learner06</td>
</tr>
</tbody>
</table>
As per Section 3.6.1, the mathematics achievement of the learners required measurement before the experiment was conducted, namely pre-tests. Accordingly, all learners wrote Pre-test One at the same time on Wednesday 07 November 2018 and all learners wrote Pre-test Two at the same time on Thursday 08 November 2018.

Then, the learners wrote Post-test One on Thursday 15 November 2018. The learners in the experimental group wrote at the same time in that class and the learners in the control group wrote at the same time in that class. The learners wrote Post-test Two on Thursday 22 November 2018. The learners in the experimental group wrote at the same time in that class and the learners in the control group wrote at the same time in that class. In addition, on each test, each child wrote his/her name and surname and the date of the test, so that the pre- and post-tests for each child could be matched accurately.

For all the pre- and post-tests, one mark was allocated for a correct answer and zero for an incorrect answer. However, after reviewing the completed tests it became apparent that many of the children were able to conceptualise the mathematics story problems correctly but their operational processing was incorrect, so it was decided to allocate a half-mark where a student correctly wrote the formula for a story sum but got the final result incorrect. For example, for the story sum, “Petrus has 76 pens and Sam has 13 pens. How many pens do they have altogether?”, if a learner wrote $76 - 13 = 63$ then that learner got zero, if the learner wrote $76 - 13 = 89$, then that learner got a half-mark, if the learner wrote $76 + 13 = 63$, then the learner got a half-mark and if the learner wrote 89 only or $76 + 13 = 89$, then the learner got one mark.

In addition, it was also evident that many of the children were not able to calculate the remainder in the division problems correctly but they were able to calculate the integer part of the answer correctly, so it was decided to allocate a half-mark where a student correctly wrote either the integer part or remainder in the division problems with remainders. Where both the integer part and remainder was correct, the learner got one mark.

However, this marking decision created a problem for the marking of Pre-test Two Question Ten and Post-test Two Question Ten, because these were division and story sums, so, the problem was that the learners were already getting half a mark for a correct formula. So, if a student got the formula correct and the integer part of the answer correct but did not get the remainder correct he/she could still get two half-marks to obtain one mark without a completely correct answer, which is not fair or defendable. So, the marking of Pre-test Two Question Ten and Post-test Two Question Ten could not accommodate both the aforementioned half-mark marking principles, namely for story sums and division with a
Chapter 4: Presentation, Analysis and Discussion of the Data

remainder. However, for both Pre-test Two Question Ten and Post-test Two Question Ten, all of the learners either got the whole answer correct or the whole answer incorrect or only the formula correct, so, the problem scenario did not occur and both half-mark marking principles could be applied fairly across all the pre- and post-tests and learners.

Each pre- and post-test for each learner was marked twice, once by the researcher and again by the supervisor and both were in exact agreement about the final marks allocated. Once all the marking was done, the total mark for each learner for each test was converted into a percentage and loaded into SPSS for analysis.

4.2.2 Analysis of the experiment’s pre- and post-test results

The results of the pre- and post-tests were analysed using t-tests as is appropriate where two groups have been created using random assignment and processed on SPSS. T-tests are used to measure statistically significant differences in the mean values between groups. Before conducting a t-test, it is important to determine if the data comply with t-test assumptions, namely approximate normality, homogeneity of variance and independence, which does not apply to a paired-samples t-test. Normality is determined by dividing skewness and kurtosis by their standard error scores and the result should fall within the values of ±1.96 (Rose, Spinks, & Canhoto, 2015). In addition, for normality, the Shapiro-Wilk test values should have a p-value greater than 0.05. All the pre-test and post-test scores for all the groups complied except the Pre-test Two scores in the experimental group, the Post-test One scores for the control group and the Post-test Two scores for the control group. Therefore, the findings from the t-test analyses involving these groups should be read with this in mind; however, there is still value in performing the t-tests since the t-test is a robust test with respect to the assumption of normality and the Levene's tests confirmed the equality of variances in the samples or homogeneity of variances (p>0.05). Thus, it was acceptable to proceed with the t-test analyses.

The first t-test was an independent samples t-test and this was done on the pre-tests only to determine if there was any significant difference between the experimental and control groups at the start. Pre-test One (p>0.05) in Table 12 and Pre-test Two (p>0.05) in Table 13 indicated that there was no significant difference between the experimental and control groups at the pre-test stage and, therefore, it suggests that no group began with a significant advantage over the other. The tables represent the output from SPSS and the p-values referred to are labelled “Sig. (2-tailed)” in the tables.
Chapter 4: Presentation, Analysis and Discussion of the Data

Table 12: Independent samples t-test for Pre-test One between the experimental and control group

<table>
<thead>
<tr>
<th>Levene's Test for Equality of Variances</th>
<th>t-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td></td>
<td>Lower</td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td>1.058</td>
<td>.343</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td>-.167</td>
</tr>
</tbody>
</table>

Table 13: Independent samples t-test for Pre-test Two between the experimental and control group

<table>
<thead>
<tr>
<th>Levene's Test for Equality of Variances</th>
<th>t-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td></td>
<td>Lower</td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td>13.500</td>
<td>.010</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td>.311</td>
</tr>
</tbody>
</table>

A similar independent samples t-test was done on the post-tests only. Post-test One (p>0.05) in Table 14 indicated no significant difference, but Post-test Two (p<0.05) in Table 15 indicated that there was a significant difference between the groups in their final multiplication and division test. However, these tests do not measure the effect of the Constructivist assistive technology on the mathematics achievement relative to the learner’s starting achievement, only that there is a significant difference at the end, which may or may not be due to the Constructivist assistive technology. So, while this test does not provide evidence of the effectiveness of the Constructivist assistive technology, the Post-test Two
significant difference between the groups provides a tentative suggestion that there may be some effect.

**Table 14**: Independent samples t-test for Post-test One between the experimental and control group

<table>
<thead>
<tr>
<th>Levene's Test for Equalities of Variances</th>
<th>t-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Sig.</td>
<td>t</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>----</td>
</tr>
<tr>
<td>S c o r e</td>
<td>Equal variances assumed</td>
<td>.278</td>
</tr>
<tr>
<td>S c o r e</td>
<td>Equal variances not assumed</td>
<td>-.649</td>
</tr>
</tbody>
</table>

**Table 15**: Independent samples t-test for Post-test Two between the experimental and control group

<table>
<thead>
<tr>
<th>Levene's Test for Equalities of Variances</th>
<th>t-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Sig.</td>
<td>t</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>----</td>
</tr>
<tr>
<td>S c o r e</td>
<td>Equal variances assumed</td>
<td>3.524</td>
</tr>
<tr>
<td>S c o r e</td>
<td>Equal variances not assumed</td>
<td>-2.961</td>
</tr>
</tbody>
</table>

Paired samples t-tests (Tables 16-19) were also done for each group between their pre- and post-test scores for each phase. All groups showed p>0.05, so that there were no statistically significant changes over the time of the study. These tests also do not measure the effect of
the Constructivist assistive technology on the mathematics achievement between the groups but they may provide information about changes in achievement within a group over time.

Table 16: Paired samples t-test for Phase One control group pre- and post-test scores

<table>
<thead>
<tr>
<th>Paired Differences</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test_Score - Post-test_Score</td>
<td>-18.75000%</td>
<td>15.47848%</td>
<td>7.73924%</td>
<td>-2.423</td>
<td>3</td>
<td>.094</td>
</tr>
</tbody>
</table>

Table 17: Paired samples t-test for Phase One experimental group pre- and post-test scores

<table>
<thead>
<tr>
<th>Paired Differences</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test_Score - Post-test_Score</td>
<td>-5.00000%</td>
<td>31.09126%</td>
<td>15.54563%</td>
<td>-3.22</td>
<td>3</td>
<td>.769</td>
</tr>
</tbody>
</table>

Table 18: Paired samples t-test for Phase Two control group pre- and post-test scores

<table>
<thead>
<tr>
<th>Paired Differences</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test_Score - Post-test_Score</td>
<td>15.00000%</td>
<td>12.90994%</td>
<td>6.45497%</td>
<td>2.324</td>
<td>3</td>
<td>.103</td>
</tr>
</tbody>
</table>

Table 19: Paired samples t-test for Phase Two experimental group pre- and post-test scores

<table>
<thead>
<tr>
<th>Paired Differences</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test_Score - Post-test_Score</td>
<td>-25.00000%</td>
<td>20.41241%</td>
<td>10.20621%</td>
<td>-2.449</td>
<td>3</td>
<td>.092</td>
</tr>
</tbody>
</table>

To test the effect of the Constructivist assistive technology on the mathematics achievement of the learners for each phase between the experimental and control groups, independent t-
Chapter 4: Presentation, Analysis and Discussion of the Data

tests were conducted on the difference between the pre- and corresponding post-test scores for each learner. For the addition and subtraction phase, Phase One, there was no statistically significant difference (p>0.05) between the control and experimental group in their changed scores, as indicated on Table 20. However, for the multiplication and division phase, Phase Two, there was a statistically significant difference (p<0.05), in Table 21. This suggests that there was a statistically significant effect of the Constructivist assistive technology on the multiplication and division achievement of the learners.

**Table 20:** Independent samples t-test on the difference in scores for each learner in Phase One between the experimental and control group

<table>
<thead>
<tr>
<th>Levene's Test for Equality of Variances</th>
<th>t-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal variances assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Sig. .</td>
<td>t</td>
</tr>
<tr>
<td>.1397</td>
<td>.282</td>
<td>-.792</td>
</tr>
</tbody>
</table>

| Equal variances not assumed            |                            |                                        |
| F                                      | Sig. .                     | t  | df  | Sig. (2-tailed) | Mean Difference | Std. Error Difference | Lower | Upper |
| -.792                                  | 4.401                      | .469 |    | -13.75000% | 17.36555% | -60.28038% | 32.78038% |

**Table 21:** Independent samples t-test on the difference in scores for each learner in Phase Two between the experimental and control group

<table>
<thead>
<tr>
<th>Levene's Test for Equality of Variances</th>
<th>t-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal variances assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Sig. .</td>
<td>t</td>
</tr>
<tr>
<td>.667</td>
<td>.445</td>
<td>3.312</td>
</tr>
</tbody>
</table>

| Equal variances not assumed            |                            |                                        |
| F                                      | Sig. .                     | t  | df  | Sig. (2-tailed) | Mean Difference | Std. Error Difference | Lower | Upper |
| 3.312                                  | 5.069                      | .021 |    | 40.00000% | 12.07615% | 9.08388% | 70.91612% |
The analyses in this section enables the study to answer Research Question Three, and, while these analyses suggest that the Constructivist assistive technology may have had a positive effect on the multiplication and division achievement of the learners, it is important to understand these findings in relation to the experiences of the teachers who are regarded as experts in the selected teaching context. The experiences of the teachers are presented in the next section.

4.3. The interviews

4.3.1 Conducting the interviews

As detailed in Section 4.2.1, there were three teachers who taught at the special school that were directly involved in the study, and they were assigned the codes MT01 to MT03. After the experiment’s Phase One and Two, the three teachers were interviewed so that the study could answer Research Questions Four and Five. The teacher interviews occurred on Friday 23 November 2018, they were face-to-face individual interviews, lasted between 30 minutes to one hour each and they took place in each teacher’s classroom.

The first interview was with the mathematics teacher who taught the addition and subtraction experimental class and the multiplication and division control class, MT01. The second was with the mathematics teacher who taught the addition and subtraction control class and the multiplication and division experimental class, MT03. The third interview was with the mathematics teacher who was deaf, MT02. During the interview with MT02, because the teacher was deaf, one of the other mathematics teachers interpreted verbally for the researcher.

The researcher used an audio recording device during each interview. The advantage of using an audio recorder was to record the exact words of the participants and to make sure that all the participants’ words were captured accurately (Halcomb & Davidson, 2006; Harding, 2013). The audio recordings also allowed the researcher to concentrate on each interviewee instead of looking down at a notebook (Fernandez & Griffiths, 2007). The audio recordings were then transcribed verbatim by the researcher using a word processor. This also improved the researcher’s familiarity with the data.

The researcher then imported the interview transcripts into the qualitative analysis software called Atlas.ti to support the qualitative analysis and coding (Smit, 2002). The software facilitated code arrangement, finding connections between codes and across interviews and it also supported theory building (Smit, 2002).
4.3.2 Analysis of the interview data

After reading through the transcripts several times, the researcher began the general sequence of initial coding, focused coding and theoretical coding over several weeks, but returned iteratively to the different coding stages as the analysis developed. In addition, the researcher wrote informal memos to expose thoughts, reflect on ideas and clarify concepts in the data.

In the interview transcripts, the interviewees explained that the Constructivist assistive technology created a learning environment where they, the teachers, became facilitators and guides instead of instructors. They found this role beneficial for teaching and the children’s learning. MT01 (line 20-21) said, “But as you can see, they now know and when I was guiding and facilitating them to which buttons to select and choose”.

Furthermore, the Constructivist assistive technology formed a learner-centred environment and the children were able to learn in groups by collaborating and cooperating to solve problems on RTS. MT01 (line 85-87) confirmed this by saying, “. . . because as they were working in groups, you can tell that the other learner is learning from the other one and they are helping each other which normally does not happen in the class”.

In addition, with RTS, the children learnt by exploring different types of problems and difficulty levels, self-assessing after each problem or session, learning from errors by instant feedback on RTS and by collaborating in their groups and seeking knowledge independently from the teacher as they cooperated or even competed in their groups to solve the problems. Moreover, each learner was able to monitor and evaluate the quality of his or her own thinking and behaviour through individualised selection of problems and the immediate feedback given, which supported self-regulating, self-reflecting, metacognitive thinking and being self-aware. This is verified by the following responses from the teachers:

. . . because the learners worked nicely in their groups. I liked the fact that the software is having the option of the learners to play in a competition which promotes good working skills and encourages them to work with one another. (MT01, line 23-26)

. . . the software gave a chance to the learners to see their results after solving the problems. This is one aspect that helps them to know and understand how well they are learning. . . . because as they were working in groups, you can tell that the other learner is learning from the other one and they are helping each other which normally does not happen in the class. (MT01, line 83-87)

Exploring the software in their groups helped them to understand the software better and as well made them feel confident to use the technology which I think it helped
them to learn and also to be excited about learning the four arithmetic operations. (MT02, line 74-77)

Learners were very quiet, active and more vigilant. I liked the fact that they did their own self-assessment at the end of every task on the software. It really encouraged them to continue and learn more. I was also very impressed to how they used the software because I did not expect them to learn that fast. So, I was very happy to see how fast they learned with the laptop. (MT03, line 63-66)

Learning was easy because they could see their own results of the problems when they use the software. (MT03, line 98-99)

All the teachers involved with the experiment were positive about teaching and learning with the Constructivist assistive technology and their most frequent comments included that it was easier to teach, it improved teaching and it made teaching fun. Their most frequent comments about their learners included that learning was easier and the learners were excited, motivated, happy, interested, enjoyed working in groups, learnt faster, performed better and were active learners. Relevant quotes from the transcripts include:

Learners were not only excited to use the software, but they wanted to solve the problems more especially when they get wrong answers. The software is also good because it has the option for the learners to see their results at the end of every task. Therefore, they can see how they are doing to solving the problems and this is good for them. I believe that teaching with technology makes the classroom fun for the learners as well so it was suitable for me. (MT01, line 29-34)

Normally, I would just stand in front of the class signing but with the software, the learners became active and they looked interested which was very surprising. (MT01, line 58-60)

Teaching was easy because learners looked like they wanted to learn more with the laptop and that made me very happy. You know, usually these learners forget at times but when I was teaching, you can see that they are picking up few things step by step with the laptop. This made me very happy. (MT01, line 63-66)

. . . the software enabled them to learn faster. So, it is a good teaching material. (MT02, line 25)

Well, both the laptop and the principles will be applicable to use because the laptop is a tool that already supports the constructivism theory and if one can use it alone then the learners may not gain any knowledge without additional principles. The only problem we have is that our learners do not use any form of technology and, well,
now with this combination, I think it is good for teaching deaf learners especially in mathematics. (MT02, line 28-32)

Before the assistive technology, learners were too slow to solve a problem. But now with the software, they are fast to submit their answers which made my teaching easier for me as well. (MT02, line 53-55)

The learners performed a lot better with the assistive technology and if it was something they could use daily, then their learning will improve. (MT02, line 69-70)

. . . the assistive technology needs to be guided by those principles and working with the technology alone will not help the learners. So, I noticed working with the technology somehow changes how the learners pick up things which is good for their learning. (MT02, line 85-88)

It was not difficult because the software is very easy to use and it’s not complicated. It does not freeze also so learning to them was easy. Even the first day that they used the laptop, they did not struggle to continue on their own. (MT02, line 104-106)

It was easy because the assistive technology is very easy to use by the learners and the principles are also easy to implement especially for the lower grades. (MT03, line 51-52)

Yes, it is suitable because the software changed their learning. These learners need this kind of learning to use with the technology and I think that it can help them perform better. (MT03, line 75-76)

Well, I could see that learners were more attentive and eager to learn. They were mostly waiting for the time that they need to use the laptops which improved their concentration in the classroom. (MT03, line 93-95)

The teachers involved also provided constructive comments for potential improvements to RTS, especially for deaf learners who were required to first learn sign language before learning subjects at school and these learners could not easily use spoken language for mathematical processes like counting, which is not an obstacle experienced by non-disabled learners. As such, the teachers recommended that in future RTS should support multiple perspectives and representations of concepts besides numbers only since deaf learners learn better with pictures, diagrams, words or even Namibian Sign Language interpretation.

The emergent categories from the interviews that related to the children’s learning during both phases of the experiment with the Constructivist assistive technology were the Constructivist-related categories of collaborating, cooperating, exploring, self-assessing,
learning from errors, seeking knowledge independently, self-regulating, self-reflecting, metacognitive thinking and being self-aware.

These concepts were referred to by the teachers as follows:

Also, principle four [Activities, opportunities, tools and environments are provided to encourage metacognition, self-analysis, self-regulation, self-reflection & self-awareness] was important for my teaching because the software supports a tool which helps these learners to understand and practice mathematics better than always relying on the textbooks. The other principle I would say is principle sixteen [Collaborative and cooperative learning are favoured in order to expose the learner to alternative viewpoints] because the learners worked nicely in their groups. I liked the fact that the software is having the option of the learners to play in a competition which promotes good working skills and encourages them to work with one another. But otherwise, I think all the principles are good for teaching. (MT01, line 21-26)

Well, I think principle twelve [Errors provide the opportunity for insight into students’ previous knowledge constructions] because the software gave a chance to the learners to see their results after solving the problems. This is one aspect that helps them to know and understand how well they are learning. I would also say principle sixteen [Collaborative and cooperative learning are favoured in order to expose the learner to alternative viewpoints] because as they were working in groups, you can tell that the other learner is learning from the other one and they are helping each other which normally does not happen in the class. (MT01, line 83-87)

. . . principle thirteen [Exploration is a favoured approach in order to encourage students to seek knowledge independently and to manage the pursuit of their goals] was also important because when they use the laptop for the first time, they needed to explore and to make sure that they understand all the keys and steps to use the laptop. (MT02, line 20-22)

. . . principle thirteen [Exploration is a favoured approach in order to encourage students to seek knowledge independently and to manage the pursuit of their goals] and principle sixteen [Collaborative and cooperative learning are favoured in order to expose the learner to alternative viewpoints] . . . (MT02, line 73)

Principle four [Activities, opportunities, tools and environments are provided to encourage metacognition, self-analysis, self-regulation, self-reflection & self-awareness] because the software encouraged the learners to understand their mistakes. For example, when they get a wrong answer for a problem, you can see them
wondering where they did wrong. So that means they are aware of what they are doing and they want to get the correct answers. (MT03, line 69-72)

Figure 16 below provides a visual representation of these conceptual categories and arranges them in relation to group and/or individual learning orientation as per the interview data.

Figure 16: Emergent categories from the interviews that related to the children’s learning with the Constructivist assistive technology

The analyses in this section enabled the study to answer Research Questions Four and Five and they provide support for the findings from the experiment’s pre- and post-tests analyses. Given the responses from the teachers, it is plausible that the Constructivist assistive technology had a positive effect on the mathematics achievement of the learners.

4.3.3 Discussion of the emergent categories from the interviews

4.3.3.1 Collaborating

Collaboration in education constitutes a joint venture between students with other students and students with teachers (Smith & MacGregor, 1992). Collaboration in a mathematics classroom is supported by learners working together in groups and students discussing and sharing ideas within the provided activities (Sofroniou & Poutos, 2016). During the
experiments, collaboration was facilitated by setting up the classroom with two learners per laptop facing the teacher. The setup allowed sharing of ideas and effective communication between the learners so that they could work together to learn and solve mathematics problems. The setup also supported effective active engagement between the learners and the teacher. RTS facilitated collaborative learning as learners shared ideas among themselves and worked in groups of two. They also assisted one another during the competitions provided by RTS. It was apparent that the teachers involved in the study were happy that RTS changed how learners learned since it enabled a collaborative environment.

In addition, successful collaborative learning requires active engagement (Nyikos & Hashimoto, 1997). This may be mutual communication between the learners and the teacher or within the learners themselves. The exchange of ideas may also increase interest among the learners and promote critical thinking (Chand, 2018). In the study, RTS created interest and excitement amongst the learners, which in turn enhanced active engagement in the classroom. These findings relate to the study by Bray (2015), who found that activities that enable students to work with one another promote active engagement and support collaboration.

4.3.3.2 Cooperating

Cooperative learning allows learners to work together in smaller groups as a team to solve a problem or a task (Matthews, Cooper, Davidson, & Hawkes, 1995). The main idea is for learners to reach a goal (Johnson, Johnson, & Smith, 1984). For example, if learners are able to share ideas and are competitive towards achieving a common goal, then they are said to learn effectively through a cooperative learning environment. Various researchers in the field of assistive technology have stated that cooperative learning is beneficial in learner-centred classrooms with disabled and non-disabled learners (Dickson & Vereen, 1983; Franklin, Peat, & Lewis, 2003; Xin, 1999; Ke & Grabowski, 2007).

Cooperative learning was evident in the study where each group shared a laptop and the goal was to solve ten problems on RTS in a game-like competition. The learners worked together to answer the questions under the guidance of their teacher. The teacher allowed the learners to take turns throughout the game which contributed to collaborative learning. RTS was crucial in the game play allowing learners to work with another and share ideas to solve the given problems. Learners also asked the teacher questions when they got stuck. Students working in a game play environment foster group cooperation which creates a high level of involvement which is essential for effective learning (Franklin, Peat, & Lewis, 2003).
Furthermore, better mathematics experience and skills in learners are expected when learning in both a cooperative environment and a computer assisted instruction setting (Xin, 1999). In addition, it was apparent during the experiment that the teacher helped the learners during the classroom activities as part of the learner-centred approach. It was also necessary at times for the teacher to assist the learners to solve the problems and make sure that there was active engagement between the learners working in the groups. This was important for cooperative learning with the use of technology (Bryant & Bryant, 1998). It has also been reported that a successful cooperative classroom environment is the one that attributes teacher’s as facilitators to make sure that learners are arranged in groups that allows cooperative learning and that there is effective communication between the teacher and the learners (Warner & Kaur, 2017).

4.3.3.3 Exploring

Learners should be allowed to discover their own knowledge through active exploration (Dalgarno, 2001) and be provided with opportunities or activities that allow them to explore in mathematics (Amoonga, 2008). Also, technology enables users to explore topics in more depth and in more interactive ways (Alagic, 2003). The teachers agreed that RTS enabled the learners to explore the mathematical concepts and operations during the experiments and the learners’ confidence was positive using RTS. This is supported in the literature which indicates the effectiveness of exploring in a mathematics classroom including teacher facilitation as a learning strategy (Manoucherhri, 1999). Another study successfully used a program that provided the opportunity for exploration among the learners and active engagement and the learners used the program to explore different trigonometric functions and representations on the program (Curri, 2012).

Exploring also depends on effective guidance by the teacher for learning with technology (Dalgarno, Kennedy, & Bennett, 2014; Runesson, 1997). The findings from the study together with previous research provide support that exploring mathematics activities using assisted technology may enhance learning. Here teachers are to provide guidance and assist learners for effective learning acquisition through exploration. In addition, findings also indicate that learning through exploring increases the level of confidence in learners which motivates them to learn more than normal traditional learning.

4.3.3.4 Self-assessing

Self-assessment enables students to reflect on the quality of their work, judge their own work and revise accordingly (Thawabieh, 2017). In other words, learners are able to check their
answers and grade themselves (Ibabe & Jauregizar, 2010), which may also be aided by technology or a computer program (Brummer, 2009). The key is to allow learners to determine where they fall short and what they need to do to meet their expectations and goals (Isabwe, 2013). Rudd and Gunstone (1993) stated that for self-assessment to be successful, it should be carried out on a daily basis where students see what they have learned, how they learned it and what learning means for them in the future.

With RTS, the learners were provided with immediate feedback for every problem displayed on the software and this allowed the learners to reflect on what they had or had not learned. In addition, the iterations of problems provided by RTS were useful for learners to master a concept through self-assessment and repetition. RTS allowed learners to make mistakes and try the problems again to master them. Self-assessing on RTS enabled the learners to understand where they required assistance and improvement and it helped with motivation. This is in contrast to the traditional classroom where the assessment used to be carried out, perhaps, once at the end of the teaching instruction and learners had to wait until the next class to receive feedback on tasks.

The findings from the study are consistent with a related study indicating that technology that provided immediate feedback and grading of marks enabled self-assessment and motivation among learners (Joglar, Martín, Manuel Colmenar, Martínez, & Hidalgo, 2010). The findings are also in line with Fageeh (2015), who reported that using technology could help learners by providing immediate feedback and giving them control of their own learning.

4.3.3.5 Learning from errors

According to Kramarski and Zoldan (2008), errors can be a source for stimulating exploration and reflection and a student should be able to analyse both the problem and solution, discover the essence of the problem and be able to identify alternatives to solve the problem. Other researchers have valued the importance of error making in mathematics and other subjects (Hartman, 2001). In addition, several researchers have supported learning with technology that provides instant feedback to learners in mathematics and supports learning from errors (Aydin, 2005; Chekour, 2017; Isabwe, 2013; Moyer-Packenham & Suh, 2012).

In the study, the learners learnt from their errors by instant feedback on RTS. The software provided immediate feedback to learners upon submitting wrong answers during classroom activities. The researcher observed that the learners were active in solving the errors since the software displayed the same problem again so that the learners could understand the problem before continuing to the next problem. The researcher also observed that during the
experiment, teachers were able to assist and guide the learners as part of teacher facilitation in a learner-centred classroom. The teachers were happy to know that learners were able to receive feedback on RTS the moment they submitted a wrong answer. This also helped the learners to reflect on the problems and use their prior knowledge to try to solve the problems. In prior research where learners used technology in mathematics learning, researchers concluded that technology provided features that enhanced the learning of students (Suppes, Holland, Hu, & Vu, 2013). Firstly, learners are provided with immediate feedback from the computer program, they are given helpful hints and their progress could be individualised depending on the learning pace of each student. By providing all this to the learners, the computer program was deemed useful for learners to create meaningful ideas with mathematics concepts. The finding correspond with a claim made by Kehrer (2013) that immediate feedback improves learning in mathematics and that the timing of feedback is important to assist with errors the learners may have during the learning process. It is also noted that struggling students improved their mathematics understanding by getting feedback from the computer (Fyfe, 2016).

4.3.3.6 Seeking knowledge independently

A component of self-directed learning through seeking knowledge independently is a process where learners take the initiative with or without the help of other learners in analysing their learning needs, goals, identifying human and material resources and choosing the appropriate learning strategies (Caravello, Jiménez, Kahl, Brachio, & Morote, 2015). When learners seek knowledge independently, they are ready to explore a subject or content, have the skill and knowledge and they regard themselves as participants in their own education (Grow, 1991). In constructivism, learners should explore concepts independently, through active collaboration and cooperation and game plays (Connors, 2007).

During the experiment, learners were allowed to seek knowledge independently on RTS especially through different types of problem value ranges such as values less than ten, less than twenty, and others and different levels of difficulty. This was evident as learners did not have to be instructed on what to do next. They took control of their own learning and sought out more problems or practiced on other arithmetic problems.

Seeking knowledge independently is also facilitated by the teacher. The class lessons took place in a constructivist classroom setting and the teachers provided scaffolding to assist the learners during the lessons. The teachers gave the learners opportunities for seeking knowledge independently within the boundaries of the lesson and provided feedback where
necessary. Other studies correspond by indicating that instructional technology improves students’ academic success through seeking information independently and learning at their own pace (Wiggins, 2015). In addition, Garthwait and Weller (2004) found that assistive technology improved engagement and motivation in learners which enabled them to work independently and increase their output during the learning process.

Although it was the first time the learners used the assistive technology, they were confident and took control of their own learning. The learners also had the opportunity to acquire skills about how to operate a laptop. The study also revealed that the learners were curious to learn with RTS and they were keen on solving the problems on their own although with assistance from the teacher. This relates to a study by Rowlands (2015) with assistive technology that enabled learners to work independently, make their own choices about using the tool and take control of their own learning. Kumar (2008) also found that when learners were learning in a conducive environment that provided accessibility to technology, and they took control of their own learning, seeking knowledge independently and at their own pace.

### 4.3.3.7 Self-regulating

Panadero and Alonso Tapia (2014) defines self-regulating as the control that students have on their own cognition, behaviour, emotions and motivation through the use of personal strategies to achieve learning goals. It is a conceptual self-directive process whereby learners transform their individual mental abilities into academic skills (Zimmerman, 2002). Several researchers indicate that self-regulating requires an active learner (Leutner, Leopold, & den Elzen-Rump, 2007; Pintrich, 2000; Zimmerman, 2002).

During the experiment, learners took control of their own learning on RTS once the teacher set the overall goals for the class. The learners developed their own ways of working with RTS to learn the mathematics concepts and controlled their pace of learning and difficulty levels on RTS. Similarly, Johnson and Davies (2014) found that students who learned in a web-based environment through self-regulation out performed those learners who did not and that self-regulation was essential to student academic achievement. In addition, Mega (2014) reported that when learners are happy and excited to learn in a constructivist assistive technology environment this promotes self-regulated learning (Panadero & Alonso Tapia, 2014). The learners in the experiment were excited and motivated to learn with RTS and this supported their self-regulating.
4.3.3.8 Self-reflecting

Self-reflection can be defined as procedure that a learner undertakes to look back on his or her previous learning experiences and what transpired then to enable new learning to occur (Lew & Schmidt, 2011). It is also defined as thinking about one’s own experiences to create awareness of thoughts, values and actions and to consider alternatives to problems (Roberts & Westville, 2008). Sharma (2012) describes reflective learning as a platform that encourages deeper learning and understanding of concepts which assists in the improvement of learning.

In this study, learners had the opportunity to self-reflect while working on RTS and considering the feedback provided about their solutions, especially in the instance where they gave incorrect answers. The teacher encouraged the learners to think about the feedback given by RTS and then try to determine where they went wrong based on their previous lessons.

Other researchers have provided positive findings about using technology integrated learning with learner-centeredness to foster self-reflection (Kori, Pedaste, Leijen, & Mäeots, 2014; Leinonen, Keune, Veermans, & Toikkanen, 2016; Mäeots et al., 2016; Qarabash, Heslop, Kharrufa, Balaam, & Devlin, 2018). Also, in another study, assistive technology offered a tool which supported reflection through technology and learners were able to think about activities, focus and review what they had done (Kori et al., 2014).

4.3.3.9 Metacognitive thinking

Metacognition is about how learners monitor and direct their own learning (Hasselhorn & Labuhn, 2011) and it is a learning strategy that allows the checking of accurate memorisation techniques or selecting an appropriate cognitive strategy for any task at hand. Metacognition has proven to be a useful concept in reading, problem-solving, attention, memory, self-cognition and self-instruction (Gama, 2005). The role of metacognition in mathematics and special education is imperative so that learners recall information they already know during classroom instruction to support new learning (Bretsch, 2017).

During the experiment, the teachers created a learning environment that allowed learners to think about their learning. For example, an activity was the introduction of word problems where learners were expected to put the word problem into an equation and vice versa. In addition, RTS provided new and varied problems activating the learners’ metacognitive processes to think about how to go about solving the problems. The learners were also able to use other objects in conjunction with RTS to assist them with counting and solving the
problems displayed by RTS. The different representations included stones and mathematics tables that were placed at each group. Because the learners counted with their fingers, they were able to guess and check the correct answer and they were able to use the strategy that was most appropriate for them. Therefore, the learners were thinking and reflecting on the problems displayed by RTS, based on what they knew before and developing learning strategies to solve those problems.

Previous studies show that metacognitive thinking is a vital factor in mathematics learning and problem solving (Mevarech & Amrany, 2008; Stillman & Galbraith, 1998). Effective metacognitive thinking allows learners to reflect on their previous knowledge when solving mathematics problems (Zepeda, Hlutkowsky, Partika, & Nokes-Malach, 2018).

4.3.3.10 Being self-aware

Self-awareness is a term that describes an individual’s self-perception, self-image and self-identity (Zhao & Zhou, 2016). Han and Kim (2016) define self-awareness as a cognitive activity or process of understanding one’s thoughts, feelings and beliefs. A crucial part of a teacher in learner-centeredness is to provide learning activities that promote self-awareness in learners (Tudor, 1993).

The teachers provided a learning environment with RTS that allowed the learners to solve problems ranging from easy to difficult. In addition, the learners were aware of what they were learning and the effort they were putting in during the teaching process. Activities during the experiment were designed to raise such self-awareness. In addition, RTS supported an environment of self-awareness through the game play where two learners solved problems in their group. If learners were able to learn from one another during the game competition, then they would become aware that they were learning, how they were learning and they were further encouraged to continue learning. The literature supports the use of games to promote self-awareness (Tsai, 2009).

Tsai (2009) stipulates that self-awareness is also contributed to by metacognitive skills such as active learning, self-regulation and self-directed learning. If learners are able to find information independently and they are confident in using the tool, then they become aware of their own learning. Therefore, learners that work actively and are self-directed become aware of their learning.

4.4 Member checking

The study conducted member checking which is considered an important requirement for research credibility and verification of a study’s theories and inferences (Shenton, 2004).
Member checking involves presenting the study’s findings to key participants to determine if the findings accurately reflect their experiences (Krefting, 1991). Accurate reflection demonstrates that the study is credible and has accurately interpreted the participants’ experiences (Krefting, 1991).

On Friday 17 May 2019, the researcher presented the study findings, in the report format applied in the paper submitted to the 2019 Annual Conference of the South African Institute of Computer Scientists and Information Technologists (SAICSIT 2019), which included the experiment and interviews, to MT01, MT02, MT03 and the school principal. The researcher explained that the paper would be presented at the conference if accepted and discussed the findings. The teachers and school principal confirmed that the findings were an accurate reflection of their experiences and did not require anything to be changed, added or removed.

4.5 Chapter summary and conclusions

Chapter Four detailed the implementation of the research methodology, explained in Chapter Three. The chapter objectives have been fulfilled by describing the participants, reporting on the implementation of the research methods, analysing the data and discussing the findings. Thus, the goal of Chapter Four has been achieved, which was to present, analyse and discuss the data gathered for answering Research Questions Three to Five and achieving Sub-objective Two.

In conclusion, Chapter Four gathered and analysed empirical evidence for further understanding any effects of Constructivist assistive technology on teaching, learning and the mathematics achievement of the learners. The analysis of the data from the experiment suggests that the Constructivist assistive technology may have had a positive effect on the multiplication and division achievement of the learners. Then, the analysis of the data from the interviews provided support for the positive findings from the experiment. The interview data indicated that it is plausible that the Constructivist assistive technology had a positive effect on the teaching, learning and mathematics achievement of the learners.

This chapter has value for academics since it demonstrated rigorous empirical work, which enabled appropriate analyses including t-tests, qualitative data analysis and member checking for answering Research Questions Three to Five. This chapter also has value for teaching practice by explaining how Constructivist assistive technology could be implemented for potential benefits to teaching and learning of children with hearing disabilities. Chapter Five follows and explains how all the research questions have been answered, the problem statement has been addressed and the research objective achieved. Furthermore, Chapter Five
Chapter 4: Presentation, Analysis and Discussion of the Data

provides the study’s recommendations, contributions, limitations and future research opportunities.
Chapter 5: Research Conclusions

5.1 Introduction
Chapter Four presented, analysed and discussed the data gathered for answering Research Questions Three to Five. The goal of Chapter Five is to present the outcomes and conclusions of the research and explain how all the study’s research questions have been answered. To achieve this goal, Chapter Five has the following objectives: to present a summary of the findings from Chapter Four and relate the findings to the literature, demonstrate that the research questions have been answered, the research problem has been addressed and the research objective achieved, provide school management and teachers with guidelines and recommendations, clarify the study’s contribution to the field and discuss the research limitations and opportunities for future research.

5.2 Summary of the findings from Chapter Four and their relation to the literature
The purpose of this study was to provide scientific evidence of the effects of Constructivist assistive technology for the deaf, specifically applied to the teaching and learning of mathematics at a rural Namibian special primary school. The analysis of the data from the experiment suggests that the Constructivist assistive technology may have had a positive effect on the multiplication and division achievement of the learners. Then, the analysis of the data from the interviews provided support for the findings from the experiment. The interview data indicated that it is plausible that the Constructivist assistive technology had a positive effect on the teaching, learning and mathematics achievement of the learners.

As per Section 2.5.3, the literature exposes the potential for assistive technology to improve the academic achievement of disabled learners (Liu, Chou, Liu, & Yang, 2006) but warns that there are many challenges with assistive technologies (Bouck et al., 2006). Accordingly, there are studies where assistive technology improved the education of disabled learners, many studies where assistive technology was not effective in improving the education of disabled learners and many that had mixed results. So, theories to guide the use of assistive technologies are necessary, and following Section 2.5.4, Constructivism appeared to be the most appropriate of the prominent learning theories reviewed to guide the use of the assistive technology in this study (Briede, 2016; Dewi & Harahap, 2016; Major & Mangope, 2012; Mihrka & Mihrka, 2014; Seekola, 2011).

Thus, the study implemented Constructivist assistive technology, which, overall, had plausibly positive results. In support, Molebash (2002) indicates that the integration of
technology in a constructivist learning environment enhances learning. Ten constructivist related categories emerged from the qualitative data analysis of the teacher interviews, namely collaborating, cooperating, exploring, self-assessing, learning from errors, seeking knowledge independently, self-regulating, self-reflecting, metacognitive thinking and being self-aware. These findings indicate that many of the eighteen principles of constructivism (Murphy, 1997) were implemented in the study and these were enabled by the assistive technology, RTS. This is expected to contribute to the potentially positive findings in the study.

The study also exposed some of the challenges that schools similar to the study’s rural Namibian special primary school may have when trying to integrate assistive technology into their classrooms. These challenges include the lack of computers and other Information and Communications Technology (ICT) resources at the school making it difficult to introduce a technology-enhanced learning environment. This is confirmed by Josua (2013), where the main challenges were having access to technology equipment to use in special schools. Matengu (2011) also stressed that the challenge of using technology in most schools in Namibia is lack of ICT tools. Various studies have also shown that lack of technology resources hinders how teachers support instruction to learners and hence are unable to effectively integrate technology into their school curriculum (Chireshe, 2013; Peters, 2003; Rakap & Kaczmarek, 2010; September 29; Uukongo, 2014).

5.3 The research problem addressed and the research objective achieved

The study’s research problem was the lack of prior research about the effects of Constructivist assistive technology in education, specifically for the deaf in Namibia, for informing Namibian teaching and providing guidance to the Namibian schools and educators. While many related studies were found that had been conducted in the developed world, as reviewed in Section 2.5.3, the Namibian context has substantial and distinctive contextual characteristics (Namibia Ministry of Education, 2013). These include resource scarcity, cultural and language differences and varying technology competencies relating to teaching and learning.

The study gathered and analysed empirical evidence for further understanding any effects of Constructivist assistive technology on teaching, learning and the mathematics achievement of the learners. The analysis of the data from the experiment suggests that the Constructivist assistive technology may have had a positive effect on the multiplication and division achievement of the learners. Then, the analysis of the data from the interviews provided
support for the positive findings from the experiment. The interview data indicated that it is plausible that the Constructivist assistive technology had a positive effect on the teaching, learning and mathematics achievement of the learners.

Thus, the study has addressed the research problem and made an original contribution to the academic body of knowledge research about the effects of Constructivist assistive technology in education, specifically for the deaf in Namibia, for informing Namibian teaching and providing guidance to the Namibian schools and educators.

### 5.4 The research questions answered

#### 5.4.1 Research Question One

The first research question is; what learning theory was appropriate to guide learning environments mediated by technology? The study answered this research question in Section 2.5.4.1. This section provided a review of prominent learning theories in education that are appropriate to guide the use of assistive technology in the study. While there were many learning theories in the literature, four prominent theories appeared to be highly relevant to the study to guide learning with assistive technology, namely Behaviorism, Cognitivism, Constructivism and Connectivism.

After reviewing and analysing each theory, Constructivism appeared to be the most appropriate for the study (Briede, 2016; Dewi & Harahap, 2016; Major & Mangope, 2012; Mihrka & Mihrka, 2014; Seekola, 2011). These authors demonstrate how learning mathematics in a Constructivist classroom facilitates learning, group work, active participation, problem-solving and critical thinking skills. Therefore, Constructivism provided the most appropriate theoretical basis for the study, which proceeded on the premise that learning is an active, constructive process.

In addition, Constructivism has been seen as a necessity in special education. This is supported by researchers such as Ernest (1992), Cobb (1994), Simon (1995), Collins and Voc (2008) and Seekola (2011). Prior research has indicated that improving mathematics education for deaf learners requires learning to be interactive between the teacher and learners as well as enhanced through visual technology-based presentations (Agrawal & Morin, 2016). Thus, the answer to Research Question One is Constructivism.

#### 5.4.2 Research Question Two

The second research question is; what available software was appropriate for studying the effects of assistive technology and was suitable for the selected learning theory? The study
answered this research question in Section 2.5.4.2. Following literature and internet searches for mathematics software applications as assistive technology, a list of ten software candidates was compiled, namely Signing Math Dictionary, Math Signer, GeePerS*Math project, Master Maths, Math Whiz, Microsoft Mathematics, Adaptive Mind Math, RekenTest Software (RTS), Mathblaster and Geometer’s Sketchpad.

These were then evaluated and the main evaluation criteria for the mathematics software applications were the research objective as stated in Section 1.5, and the potential suitability for a Constructivist classroom, being the selected learning theory. Then, subsequent evaluation criteria were: Is sign language supported? Are student grades supported? Are mathematics concepts supported? Does it have assessment features? Does it have tutorial features? Does it have learning features? Does it have video tutorials? Does it have selectable levels of difficulty? Does it have timed exercises? Does it have printable reports after each session? Is usage free? What is the availability of software? What are the installation options? What operating system is required? And what are the hardware requirements?

Out of all the applications evaluated, RekenTest Software (RTS) was the most suitable because of its extensive design and potential to support most of principles of Constructivism in a classroom, as indicated in Section 2.5.5. RTS was designed to adapt itself to a specific student, based on that student's learning. In addition, RTS was developed for both learners and teachers to make teaching and learning effective in mathematics. RTS enabled learners to practice, analyse and test arithmetic skills. The software offered problems ranging from very easy to difficult problems. Learners were also presented with a progress report for each session. Furthermore, the software was applicable to expose learners to arithmetic problems within a primary classroom setting and it matched the curriculum content of the grade three junior primary phase syllabus in Namibia. RTS also had the potential to foster a learner-centred approach by allowing learners to investigate the concepts provided by the software through exploration and discovery. Apart from supporting a learner-centred environment, RTS was user friendly and its interface was easy to use and straightforward for learners, which would motivate learners and encourage them to learn mathematics concepts independently and at their own pace. Thus, RTS was the most appropriate for studying the effects of assistive technology and suitable for the selected learning theory. This answered Research Question Two.

The findings of the research also revealed that RTS can provide a rich mathematics learning experience for deaf learners and promote collaboration, confidence and motivation to learn. Learners were more engaged with mathematics and they were committed to the tasks which
allowed them to be in control of their own learning. Generally, the learners responded well to the software.

5.4.3 Research Question Three

The third research question is; what was the effect of the Constructivist assistive technology on the mathematics achievement of the learners? The study answered this research question in Section 4.2.2 by conducting an experiment with grade three deaf learners randomly assigned to either an experimental group, which used the Constructivist assistive technology or a control group that did not use the Constructivist assistive technology and followed the traditional classroom practices.

The experiment was done in two phases. Phase One involved the mathematics concepts of addition and subtraction only and Phase Two involved the mathematics concepts of multiplication and division only. The reason for conducting two phases was primarily to address the ethical issue of withholding benefits of the study from learners in the control group (Sekaran & Bougie, 2013) and to remove social threats to validity (Eagle & Barnes, 2009). The result was that all learners got to experience using the Constructivist assistive technology during the study.

The analyses of the pre- and post-test mathematics scores, taken before and after the experiment respectively, suggest that the Constructivist assistive technology may have had a positive effect on the multiplication and division achievement of the learners only. So, while tentative, it is important to understand these findings in relation to the experiences of the teachers, who are regarded as experts in the selected teaching context. The experiences of the teachers are presented in the next sections.

5.4.4 Research Question Four

The fourth research question is; according to the teachers, who are regarded as experts in the selected teaching context, how was their teaching affected by the Constructivist assistive technology? The study answered this research question in Section 4.3.2 after conducting interviews with all the teachers involved in the experiment.

The teachers explained that the Constructivist assistive technology created a learning environment where they, the teachers, became facilitators and guides instead of instructors and they found this role beneficial for teaching. The teachers mentioned that the Constructivist assistive technology was helpful in supporting collaboration within the classroom. It also helped the teachers to engage with their learners in a collaborative manner and allowed useful communication within the classroom. In addition, the Constructivist
assistive technology helped to facilitate their teaching, encouraged the teachers and fostered a positive attitude towards teaching mathematics to the deaf learners. The Constructivist assistive technology supported an environment that allowed the teachers to be confident and motivated to teach mathematics. Furthermore, while the teachers had never taught with technology before, the use RTS still eased some of the challenges the teachers faced during traditional classroom setting, such as standing in front of the class the whole lesson, teaching with the chalkboard only and using sign language only.

Nevertheless, the teachers mentioned challenges with the Constructivist assistive technology, namely that it was difficult to integrate it into the school curriculum since it was new and there were occasions when learners were focused on or distracted by RTS when they should have been listening to the teacher.

5.4.5 Research Question Five

The fifth research question is; according to the teachers, who are regarded as experts in the selected teaching context, how were their students’ learning affected by the Constructivist assistive technology? The study answered this research question in Sections 4.3.2 and 4.3.3 after conducting interviews with all the teachers involved in the experiment.

The teachers indicated that the Constructivist assistive technology created a learner-centred environment and the children were able to learn in groups by collaborating and cooperating to solve problems on RTS. The children learnt by exploring different types of problems and difficulty levels, self-assessing after each problem or session, learning from errors by instant feedback on RTS and by collaborating in their groups and seeking knowledge independently from the teacher as they cooperated or even competed in their groups to solve the problems. Each learner was able to monitor and evaluate the quality of his or her own thinking and behaviour through individualized selection of problems and the immediate feedback given, which supported self-regulating, self-reflecting, metacognitive thinking and being self-aware. Thus, the emergent categories from the interviews that related to the children’s learning during both phases of the experiment with the Constructivist assistive technology were the Constructivist-related categories of collaborating, cooperating, exploring, self-assessing, learning from errors, seeking knowledge independently, self-regulating, self-reflecting, metacognitive thinking and being self-aware.

The answers to Research Questions Four and Five provide support for the findings from the experiment’s pre- and post-tests analyses. Given the responses from the teachers, it is
plausible that the Constructivist assistive technology had a positive effect on the mathematics achievement of the learners.

5.4.6 Research Question Six – Contributions to the field
The sixth research question is; based on the study’s results, what was learnt that could be of use to other researchers in the domain? The study presents an original contribution to the academic body of knowledge by providing rigorous empirical evidence about the effects of Constructivist assistive technology in education, specifically for the deaf in Namibia. The scientific insights that enhance the field are the positive effect of the Constructivist assistive technology on the multiplication and division achievement of the learners, the data from the interviews providing support for the positive findings from the experiment and the emergent Constructivist-related categories of collaborating, cooperating, exploring, self-assessing, learning from errors, seeking knowledge independently, self-regulating, self-reflecting, metacognitive thinking and being self-aware.

In addition, the study contributes to the field with an implementation of a pragmatist epistemology for gaining knowledge about the effects of Constructivist assistive technology for the deaf, using an experiment and interview research strategies. In addition, the study provides a useful method for reviewing and selecting an appropriate learning theory and assistive technology.

5.4.7 Research Question Seven - Guidelines and recommendations for school management, teachers and Namibian policy
The seventh research question is; based on the study’s results, what recommendations can be made for school management, teachers and Namibian policy? It is clear that children with disabilities face severe challenges when it comes to education. This study focused on an important group of disabled learners, namely deaf learners in a resource constrained environment. The study introduced Constructivist assistive technology into their mathematics learning and the findings suggest that this type of intervention may be feasible, practical and effective in such environments. Importantly, both the assistive technology and the learning theory should be compatible and implemented as a single intervention for better chances at success. For school management and teachers that teach deaf children, the paper offers an intervention with the potential for improving their teaching and their learners’ mathematics achievement. The evidence in the study should also inform Namibian policy and the educational system of Namibia.
Chapter 5: Research Conclusions

5.4.7.1 Recommendation One: Namibian Educational Policy
The vision of the Namibian Educational Policy supports a learning environment that is learner-centred (Namibia Ministry of Education, 2013). Thus, Namibian policy should encourage curriculum planning that integrates Constructivist assistive technologies for an effective learning environment and provides for the necessary physical infrastructures. This should promote effective interaction, collaboration, exploration and metacognitive thinking. In addition, other benefits such as instant feedback and assessment and self-reflection through the interactive problem solving are facilitated. Moreover, it may offer a fun, exciting and motivating learning journey for disabled learners and an effective facilitation medium between teachers and learners. The Constructivist assistive technology classroom setting also creates an environment where learners are able to take control of their own learning with guidance from a teacher. The objective is improved academic achievement by deaf learners. For successful implementation, Namibian policy should also encourage funding for learning resources such as Constructivist assistive technologies in special schools.

5.4.7.2 Recommendation Two: The Namibian Ministry of Education ICT policy
The Namibian Ministry of Education ICT policy should prioritise ICT facilities in all schools as stated in their vision 2030 mandate. In addition, although the policy promotes the use of ICT in schools, since the policy emphasizes the pedagogical use of ICT as an integrated tool in teaching and learning processes in all levels of schools in Namibia, it does not indicate the use and integration of ICT into the school curriculum (Ngololo, Howie, & Plomp, 2012). A useful enhancement to the policy could be to provide ICT services for the integration of ICT into the school curriculums. The Constructivist assistive technology used in this study could help in further reforming this policy for disabled learners. In this regard, the study provides valuable information to policy makers about integrating technology for effective learning environments.

5.4.7.3 Recommendation Three: School management and teachers & ICT infrastructure
School management and teachers should seek various avenues to fund the physical, software and networking infrastructure needed to support the use of assistive technology. Especially, in rural areas where most special schools cannot access technological tools, deaf learners remain behind in mathematics compared to their hearing peers. Since there is useful assistive technology that is freely available requiring relatively low cost computing resources, as evident in this study, it may be an achievable funding endeavour to implement such technology into their school curriculums.
5.4.7.4 Recommendation Four: School management and teachers & learning

School management and teachers should prioritise becoming familiar with technological tools and complementary learning approaches by allocating time to determine the potential benefits and challenges of these tools, especially the freely available ones. It has been noted that educators and schools often do not recognize how assistive technology may benefit learners (Edyburn, 2000) especially learners with disabilities and subjects such as mathematics. It emerged from the study that the teachers were willing to integrate Constructivist assistive technology into their classrooms and were excited about the impacts for their teaching and the children’s learning. Therefore, school management and teachers should make time to learn, practice and become skilled with technological tools and complementary learning approaches to benefit their teaching and their students’ learning.

5.4.7.5 Recommendation Five: Teachers & assistive technology

Teachers should implement assistive technology with an appropriate learning approach for improved success. Various studies have supported the use of assistive technology embedded or directed by a learning theory to supports disabled learners (Amarin & Ghishan, 2013; Gilakjani, Leong, & Ismail, 2013; Kaya, 2015). This was evident in the study and helped to create a learner-centred environment during the classroom sessions.

5.4.7.6 Recommendation Six: Teachers & Constructivism

Specifically, teachers should use a Constructivist approach in their classrooms, where effective learning is supported by effective pedagogy and knowledge acquisition that arises through a process of active construction. Emanating from the study, concepts such as collaboration, cooperation, exploring, learning from errors, self-regulating, seeking knowledge independently, metacognitive thinking, self-assessing, being self-aware and self-reflecting have been evident. Applying the eighteen principles of constructivism, as per Section 2.5.5, is particularly recommended.

5.4.7.7 Recommendation Seven: Teachers, learners & learner-centred environment.

Within a Constructivist approach, teachers should encourage collaboration between themselves and their learners so that learners are able to actively engage during classroom activities. Here, learners are able to work with one another in a learner-centred environment. In addition, teachers should create an environment where learners share ideas during mathematics activities. Thus, proper classroom arrangement is needed, as per this study, to create a successful constructivist classroom. This promotes learner skills such as team work and communication.
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5.4.7.8 Recommendation Eight: Learning from errors
There is an increasing focus of learning from errors with technology in today’s educational era. In a constructivist environment, learning often requires mistakes which learners can learn from. The study recommends allowing learners to make mistakes within an interactive program. In addition, continuous facilitation is recommended so that learners are also able to identify those errors and correct them through formative assessment instruction.

5.4.7.9 Recommendation Nine: Learning through play and exploring
Learning is supported through play and exploring. It is further recommended that in order to achieve a successful constructivist learning environment, learners should be left to discover new meaning. Teachers should thus promote exploration and play. The focus is to allow learners to seek information independently. The study found that the Constructivist assistive technology promoted independent knowledge construction by allowing learners to seek content freely. Encouragement should be given to the learners to take control of their own learning. The study recommends that teachers allow their learners to become independent information seekers rather than relying on their teachers completely.

5.4.7.10 Recommendation Ten: Learning through thinking, analysing and reflecting
Mathematics teachers should also provide activities that allow learners to think, analyse and reflect on their previous knowledge. It is important that learners are aware of what they are doing and how they are thinking. The study recommends that learners should be assisted to build on prior knowledge. As such, teaching instructions should be active and allow the learners to assess their own work to solve mathematical problems.

5.4.7.11 Recommendation Eleven: RekenTest Software (RTS)
The study demonstrated that the RekenTest Software (RTS) could be useful in a Constructivist mathematics classroom for deaf learners. RTS may have the potential to improve the mathematics achievement of deaf learners and as well increase learners’ motivation and confidence when learning arithmetic operations. This study recommends that teachers continue to test and use RTS in their mathematics classrooms. In addition, the software is freely available on the internet and it does not require the internet after installation.

5.5 Research limitations and proposals for future research
The study had limitations. The study was conducted at a single rural school in Namibia, whose characteristics may or may not be directly transferable to other countries and even
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large cities. In addition, the number of learners and teachers was small, although enough to provide useful insights to inform future research involving assistive technology for the deaf. These limitations provide valuable opportunities for further studies, including research with the constructivist assistive technology in other countries and with larger numbers of learners. Another avenue could be to study the effects of the Constructivist assistive technology on different age groups or to enhance the Constructivist assistive technology to accommodate an appropriate sign language and study the effect of the sign language versus mathematics symbols and numbers. In addition, the study only focused on mathematics as a subject and it would also be useful to study other important subjects, which include languages and sciences. Further research opportunities may include Constructivist assistive technology in inclusive classrooms where learners with and without disabilities learn together and learners with other disabilities, such as visual impairments or even multiple disabilities.

5.6 Chapter summary and conclusions

Chapter Five concluded the study by achieving the objectives of presenting a summary of the findings from Chapter Four and relating the findings to the literature, demonstrating that the research questions have been answered, the research problem has been addressed and the research objective achieved, providing school management and teachers with guidelines and recommendations, clarifying the study’s contribution to the field and discussing the research limitations and opportunities for future research. Thus, Chapter Five achieved its goal of presenting the outcomes and conclusions of the research and explaining how all the study’s research questions were answered.

Chapter Five concludes the study by explaining how the research problem was addressed or lack of prior research about the effects of Constructivist assistive technology in education, specifically for the deaf in Namibia, for informing Namibian teaching and providing guidance to the Namibian schools and educators. Chapter Five further explained that by addressing the research problem, the study is able to provide useful guidelines and recommendations for school management, teachers and Namibian policy to improve the teaching and academic achievement learners with hearing disabilities, which are both relevant, substantial and significant problems.

Chapter Five has value for academics because it demonstrated knowledge contributions about teaching and learning with Constructivist assistive technology in a primary special school classroom. Chapter Five also has value for teaching practice by providing guidelines and recommendations for school management, teachers and Namibian policy for the academic
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benefit or learners with hearing disabilities. In addition, the study informs teaching and curriculum design in special schools.
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### Appendix A: Concept-centric Literature Matrix

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Appendix B: Permission Letters from the Education Departments and the School

The signed permission letters have been removed from this appendix to maintain participant anonymity.
Appendix C: Unisa Ethics Clearance Certificate

UNISA COLLEGE OF SCIENCE, ENGINEERING AND TECHNOLOGY’S (CSET) RESEARCH AND ETHICS COMMITTEE

11 October 2018

Office of the Associate Dean
College of Humanities

Dear Ms Loide Kemanguluko Shafondyodi Abital,

Decision: Ethics Approval for 3 years
(Humans involved)

Ref #: 061/LKSA/2018/CSET_SOC
Name: Ms Loide Kemanguluko Shafondyodi Abital
Student #: 57639825

Researchers: Ms Loide Kemanguluko Shafondyodi Abital, P. O. Box 1143, Ondangwa, Namibia, 57639825@mylifg.unisa.ac.za, +264 81 336 5169

Project Leader(s): Dr Grant Howard, howargr@unisa.ac.za, +27 11 471 2273

Working Title of Research:
Constructivist Assistive Technology in a Mathematics Classroom for the Deaf: An Experiment in a Rural Namibian Primary School

Qualification: MSc in Computing

Thank you for the application for research ethics clearance by the Unisa College of Science, Engineering and Technology’s (CSET) Research and Ethics Committee for the above-mentioned research. Ethics approval is granted for a period of three years, from 11 October 2018 to 11 October 2021.

1. The researcher will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.
2. Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should be communicated in writing to the Unisa College of Science, Engineering and Technology’s (CSET) Research and Ethics Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.
Appendix D: Signed Informed Consent Forms

The signed parent-child and teacher consent forms have been removed from this appendix to maintain participant anonymity.
## Appendix E: Experiment Data Collection Instruments

### Table 22: Phase One of experiment: Pre-test One and Post-test One questions

<table>
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<tr>
<th>Test, question number, question, answer and mark allocation</th>
<th>Learning outcomes (Learners should be able to:)</th>
<th>Potential strategy for solving the question</th>
</tr>
</thead>
</table>
| Pre-test question: 1) 10 + 5 (Answer = 15) | Add a two-digit number below 100 with a one-digit number (simple addition). | Step 1: Add the numbers in the units’ place.  
Step 2: Add the numbers in the tens’ place.  
Step 3: Put the answers from the steps together. |
| 1 Mark | | |
| Post-test question: 1) 16 + 3 (Answer = 19) | | |
| 1 Mark | | |
| Pre-test question: 2) 234 + 16 (Answer = 250) | Add a three-digit number below 500 with a two-digit number (single carrying of units). | Step 1: Add the numbers in the units’ place.  
Step 2: Carry from the units to the tens.  
Step 3: Add the numbers in the tens’ place.  
Step 4: Add the numbers in the hundreds’ place.  
Step 5: Put the answers from the steps together. |
| 1 Mark | | |
| Post-test question: 2) 158 + 27 (Answer = 185) | | |
| 1 Mark | | |
Appendix E: Experiment Data Collection Instruments

<table>
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<tr>
<th>Test, question number, question, answer and mark allocation</th>
<th>Learning outcomes (Learners should be able to:)</th>
<th>Potential strategy for solving the question</th>
</tr>
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</table>
| Pre-test question: 3) 175 + 87                              | Add a three-digit number below 500 with a two-digit number (double carrying of tens and units). | Step 1: Add the numbers in the units’ place.  
Step 2: Carry from the units to the tens.  
Step 3: Add the numbers in the tens’ place.  
Step 4: Carry from the tens to the hundreds.  
Step 5: Add the numbers in the hundreds’ place.  
Step 6: Put the answers from the steps together. |
| (Answer = 262)                                              |                                                 |                                               |
| 1 Mark                                                      |                                                 |                                               |
| Post-test question: 3) 256 + 68                             |                                                 |                                               |
| (Answer = 324)                                              |                                                 |                                               |
| 1 Mark                                                      |                                                 |                                               |
| Pre-test question: 4) Petrus has 76 pens and Sam has 13 pens. How many pens do they have altogether? | Solve a story problem: Addition of two two-digit numbers below 100 without carrying. | Step 1: Interpret the story problem to mean addition.  
Step 2: Add the numbers in the units’ place.  
Step 3: Add the numbers in the tens’ place.  
Step 4: Put the answers from the steps together. |
| (Answer 76 + 13 = 89)                                       |                                                 |                                               |
| 1 Mark                                                      |                                                 |                                               |
| Post-test question: 4) Cynthia has 82 sweets. Her brother gave her 15 more sweets. How many sweets does Cynthia have in total? |                                                 |                                               |
| (Answer 82 + 15 = 97)                                       |                                                 |                                               |
| 1 Mark                                                      |                                                 |                                               |
## Appendix E: Experiment Data Collection Instruments

<table>
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<th>Test, question number, question, answer and mark allocation</th>
<th>Learning outcomes (Learners should be able to:)</th>
<th>Potential strategy for solving the question</th>
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<td>Pre-test question:</td>
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<td>5) 28 – 6</td>
<td>Subtract a one-digit number from a two-digit number below 100 (simple subtraction).</td>
<td>Step 1: Subtract the numbers in the units’ place.</td>
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<td>(Answer = 22)</td>
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<td>Step 2: Subtract the numbers in the tens’ place.</td>
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<tr>
<td><strong>1 Mark</strong></td>
<td></td>
<td>Step 3: Put the answers from the steps together.</td>
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<tr>
<td>Post-test question:</td>
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<td>5) 19 – 7</td>
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<td>(Answer = 12)</td>
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<tr>
<td>Pre-test question:</td>
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<tr>
<td>6) 368 – 49</td>
<td>Subtract a two-digit number from a three-digit number below 500 (single borrowing of tens).</td>
<td>Step 1: Subtract the numbers in the units’ place.</td>
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<td>(Answer = 319)</td>
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<td>Step 2: Borrow from the tens to the units.</td>
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<td><strong>1 Mark</strong></td>
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<td>Step 3: Subtract the numbers in the tens’ place.</td>
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<td>Step 4: Subtract the numbers in the hundreds’ place.</td>
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<td>6) 292 – 35</td>
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<td>Step 5: Put the answers from the steps together.</td>
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<td><strong>1 Mark</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test, question number, question, answer and mark allocation</td>
<td>Learning outcomes (Learners should be able to:)</td>
<td>Potential strategy for solving the question</td>
</tr>
<tr>
<td>------------------------------------------------------------</td>
<td>-------------------------------------------------</td>
<td>---------------------------------------------</td>
</tr>
</tbody>
</table>
| Pre-test question:                                         | Subtract a two-digit number from a three-digit number below 500 (double borrowing from hundreds and tens). | Step 1: Subtract the numbers in the units’ place.  
Step 2: Borrow from the tens to the units.  
Step 3: Subtract the numbers in the tens’ place.  
Step 4: Borrow from the hundreds to tens.  
Step 5: Subtract the numbers in the hundreds’ place.  
Step 6: Put the answers from the steps together. |
| 7) 275 – 86                                                 | (Answer = 189)                                   |                                             |
| 1 Mark                                                     |                                                 |                                             |
| Post-test question:                                        |                                                 |                                             |
| 7) 326 – 97                                                 | (Answer = 229)                                   |                                             |
| 1 Mark                                                     |                                                 |                                             |
| Pre-test question:                                         | Solve a story problem: Subtraction of two two-digit numbers below 100 without borrowing. | Step 1: Interpret the story problem to subtraction.  
Step 2: Subtract the numbers in the units’ place.  
Step 3: Subtract the numbers in the tens’ place.  
Step 4: Put the answers from the steps together. |
<p>| 8) There are 95 learners at Haimbili Secondary School. If 43 are boys, how many girls are at the school? | (Answer 95 - 43 = 52)                             |                                             |
| 1 Mark                                                     |                                                 |                                             |
| Post-test question:                                        |                                                 |                                             |
| 8) A bus is travelling to Windhoek with 57 passengers on board. If 24 got off at Okahandja, how many passengers are left in the bus? | (Answer 57 - 24 = 33)                             |                                             |
| 1 Mark                                                     |                                                 |                                             |</p>
<table>
<thead>
<tr>
<th>Test, question number, question, answer and mark allocation</th>
<th>Learning outcomes (Learners should be able to:)</th>
<th>Potential strategy for solving the question</th>
</tr>
</thead>
</table>
| Pre-test question:                                         | Chain sum involving addition and subtraction of three two-digit numbers below 100 (no carrying or borrowing) | Step 1: Using the first two numbers, add the numbers in the units’ place.  
Step 2: Using the first two numbers, add the numbers in the tens’ place.  
Step 3: Put the answers from the steps together.  
Step 4: Using the answer from the first two numbers and the third number, subtract the numbers in the units’ place.  
Step 5: Using the answer from the first two numbers and the third number, subtract the numbers in the tens’ place.  
Step 6: Put the answers from the steps together. |
<p>| 9) 53 + 34 - 31                                            | (Answer = 56)                                   | 1 Mark                                   |
| Post-test question:                                        |                                                |                                         |
| 9) 42 + 23 - 54                                            | (Answer = 11)                                   | 1 Mark                                   |
|                                                        |                                                |                                         |</p>
<table>
<thead>
<tr>
<th>Test, question number, question, answer and mark allocation</th>
<th>Learning outcomes (Learners should be able to:)</th>
<th>Potential strategy for solving the question</th>
</tr>
</thead>
</table>
| Pre-test question: 10) 23 + 18 - 28 (Answer = 13) 1 Mark | Chain sum involving addition and subtraction of three two-digit numbers below 100 (single carrying of units and single borrowing of tens) | Step 1: Using the first two numbers, add the numbers in the units’ place.  
Step 2: Using the first two numbers, carry from the units to the tens.  
Step 3: Using the first two numbers, add the numbers in the tens’ place.  
Step 4: Put the answers from the steps together.  
Step 5: Using the answer from the first two numbers and the third number, subtract the numbers in the units’ place.  
Step 6: Using the answer from the first two numbers and the third number, borrow from the tens to the units.  
Step 7: Using the answer from the first two numbers and the third number, subtract the numbers in the tens’ place.  
Step 8: Put the answers from the steps together. |
| Post-test question: 10) 64 + 29 - 46 (Answer = 47) 1 Mark |                                                  |                                             |
### Table 23: Phase Two of experiment: Pre-test Two and Post-test Two questions

<table>
<thead>
<tr>
<th>Test, question number, question, answer and mark allocation</th>
<th>Learning outcomes (Learners should be able to:)</th>
<th>Potential strategy for solving the question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test question: 1) 5 x 6 (Answer = 30)</td>
<td>Multiply a one-digit number with a one-digit number (simple multiplication).</td>
<td>Step 1: Recall and apply the multiplication tables.</td>
</tr>
</tbody>
</table>
| Pre-test question: 2) 58 x 3 (Answer = 174)               | Multiply a two-digit number by a one-digit number of 2, 3, 4, 5 or 10 with a product between 100 and 500 (no carrying). | Step 1: Multiply the tens’ place value of the two-digit number with the one-digit number and then multiply that answer by ten.  
Step 2: Multiply the units’ place value of the two-digit number with the one-digit number.  
Step 3: Add the two answers from steps one and two (no carrying required). |
<p>| Post-test question: 1) 8 x 7 (Answer = 56)                |                                    |                                            |
| Post-test question: 2) 47 x 4 (Answer = 188)              |                                    |                                            |</p>
<table>
<thead>
<tr>
<th>Test, question number, question, answer and mark allocation</th>
<th>Learning outcomes (Learners should be able to:)</th>
<th>Potential strategy for solving the question</th>
</tr>
</thead>
</table>
| Pre-test question: 3) 79 x 4  
(Answer = 316)  
**1 Mark** | Multiply a two-digit number by a one-digit number of 2, 3, 4, 5 or 10 with a product between 100 and 500 (single carrying of tens). | Step 1: Multiply the tens’ place value of the two-digit number with the one-digit number and then multiply that answer by ten.  
Step 2: Multiply the units’ place value of the two-digit number with the one-digit number.  
Step 3: Add the two answers from steps one and two with carrying from the tens to the hundreds. |
| Post-test question: 3) 68 x 3  
(Answer = 204)  
**1 Mark** | | |
| Pre-test question: 4) A star fish has 5 arms. How many arms are there on 8 star fish?  
(Answer 5 x 8 = 40)  
**1 Mark** | Solve a story problem: Multiplication of two one-digit numbers with a product below 100. | Step 1: Interpret the story problem to mean multiplication.  
Step 1: Recall and apply the multiplication tables. |
| Post-test question: 4) There are 6 rows of seats in a school hall. Each row has 7 seats. How many seats are there in the school hall?  
(Answer 6 x 7 = 42)  
**1 Mark** | | |
<table>
<thead>
<tr>
<th>Test, question number, question, answer and mark allocation</th>
<th>Learning outcomes (Learners should be able to:)</th>
<th>Potential strategy for solving the question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test question:</td>
<td>Solve a story problem:</td>
<td>Step 1: Interpret the story problem to mean multiplication.</td>
</tr>
<tr>
<td>5) There are 28 school bags in the classroom and there are 4 books in each bag. How many books are there in all the bags? (Answer 28 x 4 = 112)</td>
<td>Multiplication of a two-digit number by a one-digit number of 2, 3, 4, 5 or 10 with a product between 100 and 500 (single carrying of tens).</td>
<td>Step 2: Multiply the tens’ place value of the two-digit number with the one-digit number and then multiply that answer by ten.</td>
</tr>
<tr>
<td>Post-test question:</td>
<td>Step 3: Multiply the units’ place value of the two-digit number with the one-digit number.</td>
<td>Step 5: Add the two answers from steps one and two with carrying from the tens to the hundreds.</td>
</tr>
<tr>
<td>5) There are 39 boxes and inside each box there are 3 pencils. How many pencils are there in all the boxes? (Answer = 39 x 3 = 117)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Mark</td>
<td>Divide a two-digit number up to 100 by a one-digit number or 10 (simple division).</td>
<td>Step 1: Recall and apply the multiplication tables.</td>
</tr>
<tr>
<td>Pre-test question:</td>
<td>Step 2: Multiply the tens’ place value of the two-digit number with the one-digit number and then multiply that answer by ten.</td>
<td></td>
</tr>
<tr>
<td>6) 35 ÷ 7</td>
<td>Step 3: Multiply the units’ place value of the two-digit number with the one-digit number.</td>
<td></td>
</tr>
<tr>
<td>(Answer = 5)</td>
<td>Step 5: Add the two answers from steps one and two with carrying from the tens to the hundreds.</td>
<td></td>
</tr>
<tr>
<td>1 Mark</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-test question:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6) 42 ÷ 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Answer = 7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Mark</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test, question number, question, answer and mark allocation</td>
<td>Learning outcomes (Learners should be able to:)</td>
<td>Potential strategy for solving the question</td>
</tr>
<tr>
<td>-------------------------------------------------------------</td>
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</tr>
<tr>
<td>Pre-test question: 7) 84 ÷ 6</td>
<td>Divide a two-digit number up to 100 by a one-digit number or 10 (no remainder).</td>
<td>Step 1: Repeatedly subtract the divisor from the dividend until the dividend becomes zero. Borrow from the tens to the units if necessary during subtraction. Step 2: Count how many times the divisor was subtracted from the dividend until the dividend became zero.</td>
</tr>
<tr>
<td>(Answer = 14)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Mark</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-test question: 7) 91 ÷ 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Answer = 13)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Mark</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-test question: 8) 98 ÷ 8</td>
<td>Divide a two-digit number up to 100 by a one-digit number or 10 (with remainder).</td>
<td>Step 1: Repeatedly subtract the divisor from the dividend until the dividend becomes less than the divisor but more than zero. Borrow from the tens to the units if necessary during subtraction. Step 2: Count how many times the divisor was subtracted from the dividend until the dividend became less than the divisor but more than zero. The answer is the count with the remainder of the final dividend amount that was less than the divisor but more than zero.</td>
</tr>
<tr>
<td>(Answer = 12 remainder 2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Mark</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-test question: 8) 69 ÷ 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Answer = 7 remainder 6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Mark</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test, question number, question, answer and mark allocation</td>
<td>Learning outcomes (Learners should be able to:)</td>
<td>Potential strategy for solving the question</td>
</tr>
<tr>
<td>------------------------------------------------------------</td>
<td>-------------------------------------------------</td>
<td>---------------------------------------------</td>
</tr>
</tbody>
</table>
| Pre-test question: 9) There are 54 children at football practice. The coach wants to make teams of 6 children. How many teams can the coach make? | Solve a story problem: Division of a two-digit number up to 100 by a one-digit number or 10 (simple division). | Step 1: Interpret the story problem to division.  
Step 2: Recall and apply the multiplication tables. |
<p>| (Answer = 54 ÷ 6 = 9) 1 Mark | | |
| Post-test question: 9) Marco has 48 apples. He shares the apples with 8 of his friends equally. How many apples does each friend get? | | |
| (Answer = 48 ÷ 8 = 6) 1 Mark | | |</p>
<table>
<thead>
<tr>
<th>Test, question number, question, answer and mark allocation</th>
<th>Learning outcomes (Learners should be able to:)</th>
<th>Potential strategy for solving the question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test question:</td>
<td>Solve a story problem: Division of a two-digit number up to 100 by a one-digit number or 10 (with remainder).</td>
<td>Step 1: Interpret the story problem to mean division.</td>
</tr>
<tr>
<td>10) You have 80 crayons and you share them between your 6 friends equally. How many crayons does each friend get and how many are left over?</td>
<td></td>
<td>Step 2: Repeatedly subtract the divisor from the dividend until the dividend becomes less than the divisor but more than zero. Borrow from the tens to the units if necessary during subtraction.</td>
</tr>
<tr>
<td>(Answer = 80 ÷ 6 = 13 remainder 2)</td>
<td></td>
<td>Step 3: Count how many times the divisor was subtracted from the dividend until the dividend became less than the divisor but more than zero. The answer is the count with the remainder of the final dividend amount that was less than the divisor but more than zero.</td>
</tr>
<tr>
<td><strong>1 Mark</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Post-test question:

10) Nothando bakes 70 Swiss rolls for a party. She wants to put them in boxes. Each box can contain 4 Swiss rolls only. How many boxes can she fill and how many Swiss rolls are left over?

(Answer = 70 ÷ 4 = 17 remainder 2)

**1 Mark**
Appendix F: Language Editing Certificate

ACET Consultancy
Anenyasha Communication, Editing and Training
Box 50453 Bachbrecht, Windhoek, Namibia
Cell: +264814218613
Email: mlambons@yahoo.co.uk / nelsonmlambo@icloud.com

30 July 2019

To whom it may concern

LANGUAGE EDITING – LOIDE KEMANGULUKO SHAFONDYODI ABITAL

This letter serves to confirm that a MASTER OF SCIENCE (COMPUTING) thesis entitled "CONSTRUCTIVIST ASSISTIVE TECHNOLOGY IN A MATHEMATICS CLASSROOM FOR THE DEAF: AN EXPERIMENT IN A RURAL NAMIBIAN PRIMARY SCHOOL" by Loide Kemanguluko Shafondyodi Abital was submitted to me for language editing.

The thesis was professionally edited and track changes and suggestions were made in the document, which if followed by Loide Kemanguluko Shafondyodi Abital will result in a thesis with a high standard of English.

Yours faithfully

\[\text{\underline{\text{Dr N. Mlambo}}}
\]
\text{\textit{PhD in English}}
\text{\textit{M.A. in Intercultural Communication}}
\text{\textit{M.A. in English}}
\text{\textit{Postgraduate Diploma in Higher Education (i.p.)}}
\text{\textit{B. A. Special Honours in English – First class}}
\text{\textit{B. A. English & Linguistics}}
Appendix G: Originality Report

Once all the chapters of the dissertation were completed, the dissertation was submitted to Turnitin and iThenticate, which is originality checking software that looks for exact or very similar matches of words and phrases in the dissertation to those in published Internet and academic sources. The intent is to prevent plagiarism. The following filters were used:

- The references filter was activated to exclude the bibliography,
- The quotes filter was activated to exclude direct quotes,
- The word filter was activated to exclude matches that are less than 5 words, so, four words or less.

The result was a 10% similarity index as shown in the Figure F.1 below:
Appendix G: Originality Report

Constructivist Assistive Technology In A Mathematics Classroom For The Deaf: An Experiment In A Rural Namibian Primary School

**ORIGINALITY REPORT**

**10%**

**SIMILARITY INDEX**

<table>
<thead>
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<th>URL</th>
<th>Pages</th>
<th>Similarity</th>
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<td>1%</td>
</tr>
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<td>337</td>
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<td><a href="http://www.stemnet.nf.ca">www.stemnet.nf.ca</a></td>
<td>98</td>
<td>&lt; 1%</td>
</tr>
</tbody>
</table>

**Figure F.1: Filtered similarity index**

The above full report is not included in this appendix since it is longer than the entire dissertation itself. However, the above full report is available in electronic format for inspection by the reader on request. If required, please request it via the Unisa School of
Appendix G: Originality Report

Computing’s examinations contact person and provide a suitable repository for us to upload it to, such as Dropbox or Google Drive (since the file and between 40 and 50 megabytes in size, which is usually too big for e-mail).