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Erratum: Constructivism-led assistive technology: An experiment at a Namibian special primary school

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In the version of the article initially published, Abiatal, L.K.S. & Howard, G.R., 2020, 'Constructivism-led assistive technology: An experiment at a Namibian special primary school', *South African Journal of Childhood Education* 10(1), a794. https://doi.org/10.4102/sajce.v10i1.794, the article section was given incorrectly. The correct section should be Original Research instead of Review Article.

This correction does not alter the study's findings of significance or overall interpretation of the study's results. The publisher apologises for any inconvenience caused.

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Constructivism-led assistive technology: An experiment at a Namibian special primary school

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Background: The study focused on children with hearing disabilities, which was significant as almost 9 million children in sub-Saharan Africa, including Namibia, had hearing disabilities. The problem was the lack of prior research on the effects of assistive technology (AT) in primary education for the Deaf in Namibia, for guiding Namibian special primary schools and educators.

Aim: The aim was to investigate the effects of Constructivism-led AT on the teaching and learning of learners who were deaf, in a mathematics class at a rural special primary school.

Setting: The study involved Grade three children who were deaf. Grade 3 is where children learn to build and understand foundational and basic mathematical concepts, such as counting, which they require for subsequent mathematics learning and practice.

Methods: The study was a mixed-methods study comprising a quantitative experiment and qualitative interviews.

Results: The findings suggested that the Constructivism-led AT may have had a positive effect on the children's multiplication and division achievement, but not on their addition and subtraction achievement. The teachers were positive about the Constructivism-led AT and indicated that it supported collaborating, cooperating, exploring, self-assessing, learning from errors, seeking knowledge independently, self-regulating, self-reflecting, metacognitive thinking and being self-aware.

Conclusion: For school management and teachers of children who are deaf, the study offered an intervention for potentially improving teaching and their learners' mathematics achievement. In addition, the study provided valuable evidence for policymakers about integrating technology for effective learning environments.

Keywords: assistive technology; AT; Constructivism; deaf; field experiment; Grade 3; interviews; mathematics; Namibia; primary education; special education; teaching and learning.

Introduction

Social value

It has been reported that people with disabilities face many challenges (Indongo & Mufune 2015), including those related to social identity and education (Groce 2004). Ethically, children with disabilities should have the same access to education as those without disabilities (Brodin 2010) and, practically, they should have the same access to education to support themselves and to contribute to society in adulthood.

The study concerned children with hearing disabilities, which was a significant disability as deafness or partial deafness affected about 5% of the global population in 2018 or about 460 million people, with 34 million of these being children (WHO 2018). Out of these children, almost 9 million were in sub-Saharan Africa, including Namibia (WHO 2012).

Learners who are deaf experience challenges such as growing up in a family that is not proficient in Sign Language (Anglin-Jaffe 2013; Luckner, Bruce & Ferrell 2016), which is a language with grammatical rules and structure used by the Deaf and based on visual signs and gestures. In addition, having to learn from conventional textbooks can be difficult because reading skills are developed subsequent to Sign Language skills, resulting in decreased reading proficiency

(Verlinden, Zwitserlood & Frowein 2005). These challenges have been reported to foster cognitive deficits that have resulted in impaired academic achievement (Humphries et al. 2016; Luckner et al. 2016). For instance, in a report based on data from 1974 to 2003 states that learners who are deaf and hard-of-hearing typically lag behind their hearing peers in academic achievement (Qi & Mitchell 2012).

Assistive technology (AT) is defined as an approach with great potential for addressing the many challenges experienced by people with various disabilities. Assistive technology is defined as any artefact that is used to improve the functional capabilities, quality of life, autonomy and social inclusion of people with disabilities and these artefacts can be anything from cardboard communication cards to computer software (ATIA n.d.). Assistive technologies have been widely used by service providers and educators, and often in special education (Boone & Higgins 2007). There are reports of ATs having enhanced and improved the functional capabilities of students with various disabilities (Rose et al. 2005) and provided them with opportunities for independence, experience and prospects comparable to learners without disabilities (Holder-Brown & Parette 1992; Wong & Cohen 2011). In addition, it has been emphasised that ATs should be employed as early as possible to improve learning (Holder-Brown & Parette 1992).

This study targeted mathematics education as mathematics is needed everywhere in the world and all learners require mathematics, including learners who are deaf (Akpan & Beard 2014; Drouhard 2015). Furthermore, as early as possible, starting from kindergarten, young children should acquire mathematical skills, such as the ability to count, label and compare columns on graphs (Kritzer 2009). Accordingly, research to develop knowledge about how to improve the mathematics achievement of young learners who are deaf, using ATs, has important social value and was the focus of this study.

Scientific value

The principal researcher was a citizen of Namibia and, therefore, conducted the study in the Namibian context (Bruwer & February 2019). Furthermore, Namibia had committed to providing equal education opportunities to learners with disabilities under the United Nations (UN) Convention on the Rights of the Child and the Convention on the Rights of Persons with Disabilities (CRPD) (Bruwer & February 2019), which included providing support and even assistive devices to children with disabilities (MoE 2013; Namibia 2004).

Generally, it has been reported that the use of information and communications technologies (ICTs) in rural classrooms is low (Ngololo, Howie & Plomp 2012) and specifically, according to the researcher's inquiries and general knowledge, no ATs were being used for learners who were deaf in primary or even secondary schools throughout Namibia, which was substantiated in a Namibian Ministry of Education, Arts and Culture (MoEAC) report (MoEAC 2018). This was the real-world problem identified by the study. Subsequently, the literature was searched and no directly relevant research was discovered involving ATs in Namibian primary or even secondary education for the Deaf, for informing educational policy and providing guidance to the special schools and educators. Nonetheless, many studies were discovered that had been conducted in other countries, especially developed countries, but these did not relate well to the substantial and distinctive contextual characteristics in Namibia (MoE 2013), namely resource scarcity, cultural and language differences and varying technology competencies relating to teaching and learning (Bruwer & February 2019).

Consequently, the study's research problem was the lack of prior research on the effects of ATs on mathematics learning in primary education for the Deaf in Namibia and by addressing this research problem, the study made an original contribution to the scientific body of knowledge. Importantly, the study's selected rural special primary school was based on its accessibility and contextual characteristics, which placed its learners who were deaf at a high risk of low academic achievement (MoE 2013).

Conceptual framework

The literature indicated that ATs have the potential to improve the education of special needs learners. Nevertheless, there were AT studies that showed positive results (Shepherd & Alpert 2015), negative results (Koester & Mankowski 2014) and even mixed results (Foley & Masingila 2015). This demonstrated to the researchers that AT alone, whilst promising, was not a panacea for special needs education. Upon further study, it became apparent from the literature that an AT should be implemented in conjunction with a complementary learning theory for the improved chance of success (Duhaney & Duhaney 2000; Gilakjani, Leong & Ismail 2013).

The literature was then searched for potential learning theories, which presented many. After initial analysis, four learning theories, namely Behaviourism (Ertmer & Newby 2013), Cognitivism, Constructivism and was not considered ideal for mathematics learning because Behaviourist learning environments are typically passive and learners become active only by reacting to stimuli.

Cognitivism addressed some criticisms of Behaviourism emphasising the mental structures of learning and gives the mind primacy in the creation of meaning (Anderson, Reder & Simon 1997). Nonetheless, Cognitivism has been criticised for excluding the creation of meaning through social and individual experiences, which were important in the study. Similarly, Connectivism, which is a contemporary learning theory established for learning through networking in a digital environment (Goldie 2016), was not considered the best fit for the study as it is based on highly networked digital learning environments and the study's context could not support such an environment.

In contrast, Constructivism advocates that learners construct knowledge and meaning based on their interpreted experiences of the world. In a Constructivist classroom, the teacher is a facilitator and learners actively construct knowledge by participating and interpreting ideas from social and individual experiences and prior knowledge, which is deemed to have positive effects on learning and academic attitude (Semerci & Batdi 2015). Constructivism has been seen as a necessity in special education (Cobb 1994) and the integration of Constructivism in mathematics learning has been reported by several researchers to have facilitated learning, group work, active participation, problem-solving and critical thinking (Briede 2016; Major & Mangope 2012). Therefore, Constructivism was judged to provide the appropriate conceptual framework for guiding the use of the AT in the study.

Aim and objectives

The research objective was to investigate the effects of Constructivism-led AT on the teaching and learning of learners who were deaf, in a mathematics class at a rural special primary school. Accordingly, the study's research questions were:

- What was the effect of the Constructivism-led AT on the mathematics achievement of the learners?
- What were the teachers' perceptions of the Constructivism-led AT?

Research methods and design

Study design

The study was based on the philosophical position of pragmatism, an epistemology where knowledge is acquired through research strategies and methods most appropriate to answer the research questions and address the research problem (Creswell 2009). Pragmatism justified the use of mixed methods comprising an experiment (Sekaran & Bougie 2013) which used quantitative data to measure the mathematics achievement of the learners, and an interview survey (Myers 2013) using qualitative data to understand the perceptions of the teachers.

Setting

The study involved Grade 3 children who were deaf; this grade was selected because it is a grade where children learn to build and understand foundational and basic mathematical concepts such as counting, which they require for subsequent mathematics theory and practice (Rudasill, Gallagher & White 2010). In addition, Grade 3 was perceived by the researcher and teachers at the school to be the lowest grade level appropriate for conducting the experiment and for understanding the instructions and communication relating to the purposes of the study.

The children were taught written English and Namibian Sign Language (NSL) at the school. The special school was a small school with low numbers of students in each grade. Grade 3 had eight learners in 2018. This corresponded to the small population of learners who were in rural Deaf schools in Namibia (Hunter 2017). In addition, using small numbers for AT experiments in education is not unprecedented and has provided valuable insights and contributions to the field. For example, a study that tested an AT application for learners with dyslexia used only seven primary school students (Fälth & Svensson 2015) and a study that tested mobile phone usability used 18 participants (Liu et al. 2010).

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 whereas external validity is about establishing whether or not any discovered cause-and-effect relationships apply equally to other settings and scenarios. This study aimed for internal validity to address its research problem.

The particular AT used in the study was selected following an in-depth review and selection process. Initially, the researcher scrutinised the academic literature for mathematics software applications or ATs used in similar research contexts and then searched the general internet for applicable mathematics software applications. Both methods of searching resulted in a list of 10 software applications, namely Signing Math Dictionary, Math Signer, GeePerS*Math, Master Maths, Math Whiz, Microsoft Mathematics, AdaptiveMind Math, RekenTest, Math Blaster and Geometer's Sketchpad.

Each software application was evaluated for its suitability to the resource-constrained rural Namibian primary school environment and its adaptability to a Constructivist classroom (Murphy 1997). This meant that the software application had to preferably be freely available, not require internet connectivity or high-specification computing devices, use NSL or written English (Murphy 1997).

After evaluating each software application, the following were not selected: Signing Math Dictionary because it offered signing in American Sign Language (ASL) and Signed English (SE) only; Signing Math Dictionary because it was a dictionary with limited examples of mathematics terms and did not have any exercise features; Math Signer because the authors and contacts on the application's website could not be reached to gain access to the application; GeePerS*Math because it offered signing in ASL only and was not available to test via the Android app store as advertised; Master Maths, Math Whiz, AdaptedMind Math and Math Blaster because these were not freely available and had features similar to the other applications; Microsoft Mathematics because it was more applicable to higher-level grades such as Grades 8–12; and the Geometer's Sketchpad because it offered mostly geometry-based tutorials.

RekenTest (RT) (Runhaar 2016) was the software selected for the study, for its suitability to the resource-constrained rural Namibian primary school environment and its adaptability to a Constructivist classroom (Murphy 1997). Some of the key features of RT were that it was designed to adapt itself to a specific student based on a student's individual learning; it was developed for both learners and teachers; it enabled learners to practice, analyse and test their arithmetic skills; it offered problems ranging from the easy to difficult; and it allowed learners to see a progress report after each session. In addition, RT had the potential to foster a learner-centred approach by allowing learners to investigate mathematics concepts through exploration and discovery. RekenTest was designed for easy use by young children and straightforward administration by older children and adults. It therefore did not require any formal training or specialised computing skills. Its interface was simple to use, which motivated and encouraged learners to study the mathematics concepts independently and at their own pace. Furthermore, RT provided arithmetic problems for primary school grades that matched well with the curriculum content of the Grade 3 junior primary phase syllabus in Namibia.

Importantly, RT was not marketed and did not claim to be designed as an AT for the Deaf or Constructivist software and by itself cannot be regarded as Constructivist software. However, as the study used RT to improve the functional capabilities of the learners who were deaf, RT in the study is an AT by definition. In addition, the study viewed RT as an instructional tool like other instructional tools at a teacher's disposal, such as a blackboard, textbook, projector or abacus, and an instructional tool can be used in many ways by a teacher depending on that teacher's approach. Similarly, RT can be used in many ways in a classroom. The literature indicated that there was an increased chance of success if an AT is implemented in conjunction with a complementary learning theory (Duhaney & Duhaney 2000; Gilakjani et al. 2013). Accordingly, the study embedded RT in a Constructivist classroom or learning environment and used RT specifically in terms of Constructivist principles (Murphy 1997) in an experiment to measure Constructivism-led AT.

Study population and sampling strategy

There were eight learners in Grade 3 in 2018, all boys. Their specific ages were not requested as the researcher did not interact with the learners directly, but on observation they all appeared to be within the 9 to 10 year age range. In addition, their presence in the Grade 3 class provided confirmation that their competencies were at Grade 3 level and the study focused on whether or not there would be an improvement in their current academic achievement regardless of age. None of the learners had ever used a computer before the experiment and, consequently, they all started from a comparable position of no experience with computers, laptops or RT. Therefore, the first lesson of each phase of the experiment was used to guide the learners from opening the laptops to starting RT and navigating through its different settings until they were comfortable using RT on their own.

Random assignment was used to allocate the Grade 3 learners into either the experimental/treatment group or the control group. Randomised experiments are regarded as an effective method for assessing an intervention between two groups in educational research (Campbell, Cook & Shadish 2002; Sekaran & Bougie 2013). Random assignment ensured that each learner had an equal chance of being assigned to either group; any confounding variables were distributed equally amongst the groups and threats to the internal validity of the study were mitigated (Sekaran & Bougie 2013). Random assignment ensured that both groups were comparable.

In addition, three teachers who taught at the special school were involved in the study and they were referred to a MT01, MT02 and to MT03, where MT refers to mathematics teacher. These teachers were selected because they were employed at the school and recommended by the principal of the school as being competent and familiar with teaching the Grade 3s in the school. MT01 was a Grade 3 mathematics teacher with hearing, MT02 was a Grade 1 mathematics teacher who was deaf and MT03 was a Grade 2 mathematics teacher with hearing; and all three teachers were proficient in NSL. Whilst only two teachers were required to teach the experimental and control group classes, MT02 was included to gain further insight from the perspective of a teacher who was deaf. MT02 did not teach any of the experimental or control classes during the study but did attend all of the experimental classes to observe and, on a few occasions, observed in the control classes. Table 1 shows the allocation of the learners and teachers to the experimental and control groups.

Intervention: The experiment

The experiment was 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 was to address the ethical issue of withholding benefits of the study from learners in the control group and to remove social threats to validity (Sekaran & Bougie 2013). Therefore, the learners who 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. The result was that all the learners experienced the Constructivism-led AT during the study.

The experiment was conducted over two weeks: Phase One during the first week and Phase Two during the second week,

TABLE 1: Allocation of learners and teachers to the experimental and control groups in Phase One (addition and subtraction) and Phase Two (multiplication and division).

Learner codes	Phase One group	Phase One teacher	Phase Two group	Phase Two teacher
Learner01 Learner03 Learner04 Learner06	Experiment	MT01 MT02	Control	MT01
Learner02 Learner05 Learner07 Learner08	Control	MT03	Experiment	MT02 MT03

MT, mathematics teacher.

at the special school in the afternoons after normal school classes only, which began on Friday 09 November 2018 and finished on Thursday 22 November 2018. Two classrooms were used for the study – one for the experimental group and another for the control group.

Before the experiment began, the researcher conducted training with the mathematics teachers involved to ensure that they were familiar with the Constructivism-led AT, Constructivist principles and the study's empirical work plan. Also, the researcher made sure that the laptops and related facilities were in place and ready for the experiment.

The control group was taught the same concepts as the experimental group, except using traditional classroom principles, without the Constructivism-led AT. For both phases the experimental group's classroom had RT installed on two laptops as stand-alone installations and the learners could access RT without needing internet access. Each laptop was placed on a desk and the two desks were arranged in a semi-circular shape facing the blackboard and the teacher's desk. Two learners were assigned to each desk. The researcher was seated at the back of the classroom to avoid distracting the teaching process, to observe, make notes and be available to provide support in case there were any problems with the laptops and/or RT. The researcher had no direct contact with any of the learners and did not interfere with the teaching and learning during the study.

Data collection

The experiment: Data collection tools

In order to measure the effect of the Constructivism-led AT, the mathematics achievement of the learners required measurement before the experiment was conducted, namely a pre-test, and after the experiment was conducted: a post-test.

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 and are generally accepted measures for evaluating learning (Bragg 2012). The learners in the study had experienced achievement tests in the normal course of their schooling. For each item in each achievement test, a child who responded correctly was deemed to have demonstrated mathematics achievement of that particular concept (Bragg 2012). The mathematics achievement tests were administered as pre- and post-tests during the experiment.

The pre-tests assessed the learners before implementing the treatment whilst the post-tests assessed the learners after implementing the treatment. For each phase of the experiment, the format of the questions was the same for each pre- and corresponding post-test, except that the specific values were different. This ensured that the identical mathematical concepts were being tested, that the learners required application of the necessary mathematical reasoning and that they could not rely on memory and recall based on the pre-tests. Each pre- and post-test comprised 10 items only, as the learners were in Grade 3 and the mathematics conceptual scope for the experiment was limited to addition, subtraction, multiplication and division in the Grade 3 mathematics curriculum.

The pre- and post-tests were designed by the researcher and aligned to the objectives and specifications of the curriculum standard for the junior primary phase in Namibia (NIED 2014) as well as Grade 3 mathematics textbooks. In addition, the mathematics teachers at the school where the data were collected were consulted to verify that the test items accurately measured the required Grade 3 mathematics concepts. These design procedures promoted validity and reliability.

Furthermore, the reliability of the stydy's pre- and post-tests was measured using Cohen's kappa, which is a measure of rating agreement that corrects for chance agreement (Antia et al. 2009). Cohen's kappa required two raters, who were two of the teachers involved in the study, to rate the final questions designed by the researcher on the pre- and post-tests with a 'Yes, the question is appropriate' or 'No, the question is not appropriate'. On all of the tests, both raters were in complete agreement on what was appropriate, not appropriate and how to change the inappropriate items. It was only on the addition and subtraction pre-test and corresponding post-test that both raters indicated four items which should be changed in format only, from horizontal format to vertical. There were no problems with any of the numbers or calculations in any of the tests. All recommendations were acknowledged and the affected items were changed accordingly.

The experiment: Collecting the data

All of the learners wrote Pre-test One together on Wednesday 07 November 2018 and Pre-test Two together on Thursday 08 November 2018. Then, the learners wrote Post-test One on Thursday 15 November 2018, at the end of Phase One, and Post-test Two on Thursday 22 November 2018, at the end of Phase Two. In addition, on each test, each child wrote his name and surname and the date of the test, to accurately match the pre- and post-tests for each child during analysis.

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

The interviews: Data collection tool

The interviews collected qualitative data, which were voice recorded, transcribed and then analysed using appropriate data analysis techniques and software called ATLAS.ti.

The software facilitated code arrangement, finding connections between codes and across interviews and supported theory building. Also, in preparation for the interviews, an interview guide was developed (Myers 2013) and pre-tested with a teacher other than those involved in the experiment. The purpose was to expose any ambiguities, grammatical problems or other weaknesses and to enable refinements before the interview commenced.

Qualitative research quality is assessed differently from that of quantitative research and involves the concept 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 to internal validity, confirmability to objectivity and dependability to reliability (Shenton 2004).

The study supported transferability by providing rich detail about the context of the fieldwork, interviewees' responses and resulting analyses to enable a reader to decide whether or not the findings can be justifiably applied to similar contexts. Credibility relates to whether or not a true depiction of the study's phenomena is presented and was established 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. 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, procedures and corresponding findings. Dependability was maintained by providing comprehensive, detailed and cohesive accounts of the research from problem inception to final conclusions, enabling replication studies.

The interviews: Collecting the data

After both phases of the experiment, the three teachers involved in the experiment were interviewed on Friday 23 November 2018 in face-to-face individual interviews that lasted between 30 minutes and 1 hour and took place in each teacher's classroom. The first was with MT01, the second was with MT03 and the third interview was with MT02. During the interview with MT02, because the teacher was deaf, one of the other mathematics teachers interpreted verbally for the researcher.

Data analysis

The experiment

The pre- and post-test results were analysed using *t*-tests, which are appropriate to measure differences in the mean values between two groups with one independent and one dependent variable. These *t*-tests can be used in educational research involving small sample sizes (De Winter 2013). 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 (although independence does not apply to paired samples *t*-tests). Normality is determined by dividing skewness and kurtosis by the 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 of the pre- and post-test scores for all of the groups complied with these normality assumptions, 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 was still value in performing the *t*-tests as 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 the homogeneity of the variances ($p > 0.05$), except for the independent samples *t*-test for Pre-test Two. In this case, it meant that the variability in the Pre-test Two experimental and control groups was significantly different. However, the SPSS output, Table 3, takes this into account in a separate results row called 'Equal variances not assumed'.

The interviews

After reading through the transcripts several times, the researcher began the sequence of initial coding, focused coding and theoretical coding over several weeks, but returned iteratively to the different coding stages as the analyses developed (Corbin & Strauss 2008). In addition, the researcher wrote informal memos to expose thoughts, reflect on ideas and clarify concepts in the data.

Results

The experiment

The first *t*-test that was conducted was an independent samples *t*-test and was carried out on the pre-tests only to determine if there were any significant differences between the experimental and control groups at the start. Pre-test One ($p > 0.05$) in Table 2 and Pre-test Two ($p > 0.05$) in Table 3 indicated that there were no significant differences between the experimental and control groups at the pre-test stage and, therefore, suggested that no group began with a significant advantage over the other.

A similar independent samples *t*-test was performed on the post-tests only. Post-test One ($p > 0.05$) indicated no significant difference, but Post-test Two ($p < 0.05$) indicated that there was a significant difference between the groups in their final multiplication and division test. However, these tests did not measure the effect of the Constructivism-led AT on the mathematics achievement of the learners relative to their starting achievement; instead, it only indicated that there was a significant difference at the end, which may or may not have been due to the Constructivism-led AT. So, whilst this test did not provide evidence of the effect of the

Constructivism-led AT, the significant difference between the Post-test Two groups provided a tentative suggestion that there may have been some effect.

Paired samples *t*-tests were also performed for each group between their pre- and post-test scores for each phase. All groups showed $p > 0.05$, indicating no statistically significant changes over the time of the study. These tests also did not measure the effect of the Constructivism-led AT on the mathematics achievement between the groups, but did provide information about changes in achievement within the groups over the study duration.

To test the effect of the Constructivism-led AT on the mathematics achievement of the learners for each phase between the experimental and control groups, independent *t*-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 groups, as indicated in Table 4. However, for the multiplication and division phase, Phase Two, there was a statistically significant difference ($p < 0.05$), as indicated in Table 5. This suggested that there may be a statistically significant effect of the Constructivism-led AT on the multiplication and division achievement of the learners.

Where there is a statistically significant difference, it is useful to provide a measure of the size of that difference or effect size. A common measure of effect size is Cohen's d, which was calculated to be 2.34 for the significant difference in scores in Phase Two between the experimental and control groups. This effect size was interpreted to mean that the Constructivism-led AT improved the learners' marks in the Phase Two experimental group, on average, just over two standard deviations in comparison to the control group. This is considered a large effect size. For additional context, the actual Phase Two difference in the means was 40%, as evident in Table 6.

The analyses in this section enabled the study to answer Research Question One and suggested that the Constructivism-led AT may have had a positive effect on the multiplication and division achievement of the learners. Nevertheless, the perspective of the teachers, who were regarded as competent and familiar in the teaching context,

TABLE 2: Independent samples *t*-test for Pre-test One between the experimental and control groups.

Group variances assumption	Levene's test for equality of variances		*t*-test for equality of means						
	F	Sig.	*t*	df	Sig. (2-tailed)	Mean difference (%)	Std. error difference (%)	95% confidence interval of the difference	
								Lower (%)	Upper (%)
Equal variances assumed	1.058	.343	−.167	6	.873	−2.50000	14.93039	−39.03336	34.03336
Equal variances not assumed			−.167	4.601	.874	−2.50000	14.93039	−41.90261	36.90261

F, Levene's test statistics; Sig., significance (two-tailed *p*-value associated with the null that the two groups have the same variance [part of the Levene's test]); t, *t*-statistics under the two different assumptions: equal variances and unequal variances; Std., standard; df, degrees of freedom.

TABLE 3: Independent samples *t*-test for Pre-test Two between the experimental and control groups.

Group variances assumption	Levene's test for equality of variances		*t*-test for equality of means						
	F	Sig.	*t*	df	Sig. (2-tailed)	Mean difference (%)	Std. error difference (%)	95% confidence interval of the difference	
								Lower (%)	Upper (%)
Equal variances assumed	13.500	.010	.311	6	.766	2.50000	8.03638	−17.16430	22.16430
Equal variances not assumed	-	-	.311	3.870	.772	2.50000	8.03638	−20.11177	25.11177

F, Levene's test statistics; Sig., significance (two-tailed *p*-value associated with the null that the two groups have the same variance [part of the Levene's test]); t, *t*-statistics under the two different assumptions: equal variances and unequal variances; Std., standard; df, degrees of freedom.

TABLE 4: Independent samples *t*-test on the difference in scores for each learner in Phase One between the experimental and control groups.

Group variances assumption	Levene's test for equality of variances		*t*-test for equality of means						
	F	Sig.	*t*	df	Sig. (2-tailed)	Mean difference (%)	Std. error difference (%)	95% confidence interval of the difference	
								Lower (%)	Upper (%)
Equal variances assumed	1.397	.282	−.792	6	.459	−13.75000	17.36555	−56.24198	28.74198
Equal variances not assumed	-	-	−.792	4.401	.469	−13.75000	17.36555	−60.28038	32.78038

F, Levene's test statistics; Sig., significance (two-tailed *p*-value associated with the null that the two groups have the same variance [part of the Levene's test]); t, *t*-statistics under the two different assumptions: equal variances and unequal variances; Std., standard; df, degrees of freedom.

TABLE 5: Independent samples *t*-test on the difference in scores for each learner in Phase Two between the experimental and control groups.

Group variances assumption	Levene's test for equality of variances		*t*-test for equality of means						
	F	Sig.	*t*	df	Sig. (2-tailed)	Mean difference (%)	Std. error difference (%)	95% confidence interval of the difference	
								Lower (%)	Upper (%)
Equal variances assumed	.667	.445	3.312	6	.016	40.00000	12.07615	10.45073	69.54927
Equal variances not assumed	-	-	3.312	5.069	.021	40.00000	12.07615	9.08388	70.91612

F, Levene's test statistics; Sig., significance (two-tailed *p*-value associated with the null that the two groups have the same variance [part of the Levene's test]); t, *t*-statistics under the two different assumptions: equal variances and unequal variances; Std., standard; df, degrees of freedom.

TABLE 6: Group statistics for the difference in scores for both groups in Phase One and Phase Two.

Group	*N*	Difference in scores mean (%)	Difference in scores std. deviation (%)	Difference in scores std. error mean (%)
Phase One experiment group	4	5.0000	31.09126	15.54563
Phase One control group	4	18.7500	15.47848	7.73924
Phase Two experiment group	4	25.0000	20.41241	10.20621
Phase Two control group	4	−15.0000	12.90994	6.45497

Std., standard.

were also important for understanding the effect of the Constructivism-led AT.

The interviews

From the interview transcripts, it was apparent that the Constructivism-led AT created a learning environment where the teachers became facilitators and guides instead of instructors. The teachers found this new role beneficial for teaching and the children's learning. MT01 (lines 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' (mathematics teacher). The children were also able to learn in groups by collaborating and cooperating to solve problems on RT. MT01 (lines 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.' (mathematics teacher)

With RT, the children learnt by exploring different types of problem and difficulty level, self-assessed after problems or sessions, learnt from errors through instant feedback on RT, collaborated in their groups and sought knowledge independently from the teacher as they cooperated or even competed in their groups to solve problems. Moreover, each learner was able to monitor and evaluate the quality of his own thinking and behaviour through an individualised selection of problems and immediate feedback, 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 [*allowing*] the learners to play in a competition which promotes good working skills and encourages them to work with one another.' (MT01, mathematics teacher, lines 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.' (MT01, mathematics teacher, lines 83–84)

> '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, mathematics teacher, lines 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, mathematics teacher, lines 63–66)

> 'Learning was easy because they could see their own results of the problems when they use the software.' (MT03, mathematics teacher, lines 98–99)

All the teachers involved with the experiment provided positive feedback about teaching and learning with the Constructivism-led AT and frequent comments included that it was easier to teach, it improved teaching, it made teaching fun, learning was easier, and the learners were excited, motivated, happy, interested, enjoyed working in groups, learnt faster, performed better and were active learners.

The emergent Constructivist-related categories from the interviews were: 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.' (MT01, mathematics teacher, lines 21–26)

> 'Well, I think principle twelve [Errors provide the opportunity for insight into students' previous knowledge constructions] ... I would also say principle sixteen ...' (MT01, mathematics teacher, lines 83–84)

> '... 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, mathematics teacher, lines 20–22)

> '... principle thirteen and principle sixteen ...' (MT02, mathematics teacher, line 73)

> 'Principle four 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 [*what*] they did wrong. So that means they are aware of what they are doing and they want to get the correct answers.' (MT03, mathematics teacher, lines 69–72)

Figure 1 provides a visual representation of these conceptual categories arranged in relation to group and/or individual learning orientation.

The teachers also provided constructive comments for potential improvements to RT for learners who are deaf.

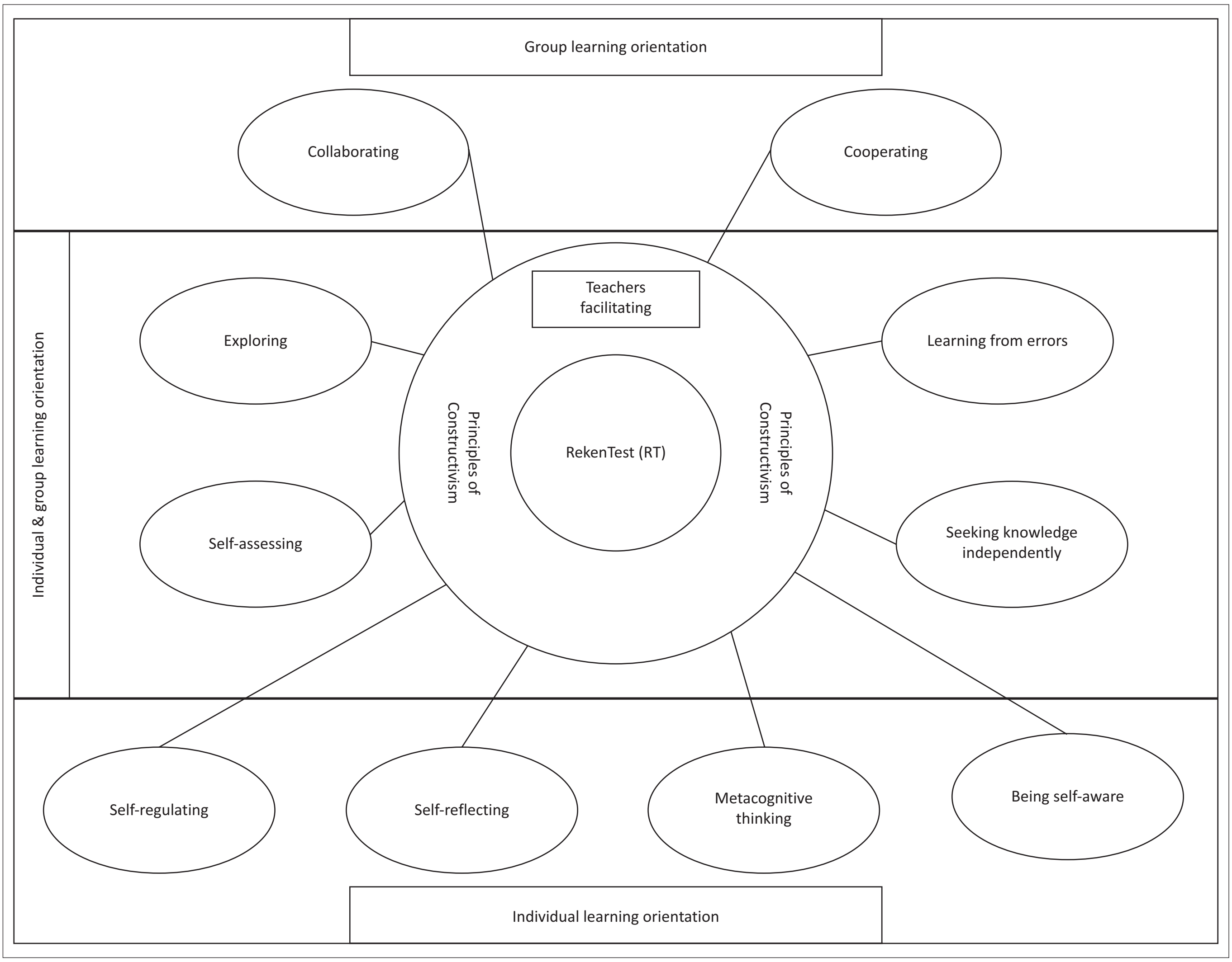

FIGURE 1: Emergent categories from the interviews that relate to the children's learning with the Constructivism-led assistive technology.

Learners who are deaf have specific needs as they are required to first learn Sign Language before learning subjects at school and cannot easily use spoken language for mathematical processes like counting. The teachers recommended that RT should support multiple perspectives and representations of concepts, besides numbers only, as learners who are deaf learn better with pictures, diagrams, words or even NSL interpretation.

The analyses from the interview data enabled the study to answer the second research question and provided support for the findings from the experiment. Given the responses from the teachers, it was plausible that the Constructivism-led AT could have had a positive effect on the mathematics achievement of the learners.

The study also 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 a study's findings to the key participants to determine if the findings accurately reflect their experiences (Krefting 1991). On Friday 17 May 2019, the researcher presented the findings, including the experiment and interviews, to MT01, MT02, MT03 and the school principal 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.

Ethical consideration

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 obtained from the principal of the special school. In addition, ethical clearance was obtained from the Unisa College of Science, Engineering and Technology (CSET) and the School of Computing Research and Ethics Committees before any data were collected, with ethical clearance number 061/LKSA/2018/CSET_SOC. Also, as the Grade 3 children participating in the study were below the age of 18, permission from each child's parents or guardians was required before their child could participate. For the interview survey part of the study, each interviewee was required to provide informed consent before his or her interview.

Participation was voluntary; they could withdraw at any time without providing a reason and participant identities were not disclosed in any publications.

Discussion

Key findings

Constructivism was assessed to be the most appropriate learning theory to guide the use of the AT in the study, as it facilitated learning, group work, active participation, problem-solving and critical thinking skills and has been viewed as a necessity in special education. The study selected RT as the AT in the study because of its suitability to the resource-constrained rural Namibian primary school environment and its adaptability to a Constructivist classroom.

The analyses of the pre- and post-test mathematics scores suggested that the Constructivism-led AT may have had a positive effect on the multiplication and division achievement of the learners, but not on the addition and subtraction achievement. Nonetheless, the teachers were positive about the Constructivism-led AT. The emergent Constructivist-related categories from the interviews were: collaborating, cooperating, exploring, self-assessing, learning from errors, seeking knowledge independently, self-regulating, self-reflecting, metacognitive thinking and being self-aware.

Discussion of key findings

The literature highlights the many challenges that schools experience when catering for learners with disabilities (Chireshe 2013; Uukongo 2014), including technology-specific challenges such as the lack of ICT and other resources (Josua 2013; Matengu 2011). The study addressed one of these school contexts and provided a cost-effective and relatively low-resource AT solution with scientific evidence of its effectiveness for improving both teaching and learning, and such research is supported by the literature (Belcastro 2004).

The study's AT was guided by Constructivist theory, and the 10 Constructivist-related categories that were evident from the qualitative data analysis indicated that instructional tools like RT, which were not designed specifically for Constructivism, could be adapted and used according to the principles of Constructivism (Murphy 1997). The study's positive results correspond with the literature that promotes integrating technology to a Constructivist learning environment to enhance learning (Duhaney & Duhaney 2000; Gilakjani et al. 2013; Molebash 2002). Against the background of literature that shows postitive, negative and even mixed results from learning with AT, the study provides guidance by demonstrating that Constructivism-led AT could be an approach for increasing the likelihood of AT teaching and learning success.

Strengths and limitations

The study's limitations include that it was conducted at a single rural school in Namibia, whose characteristics may or may not be directly transferable to other countries or even large cities. In addition, the number of learners and teachers was low, although they were enough to provide useful insights to inform future research involving Constructivism-led AT for the Deaf.

Nonetheless, these limitations provide valuable opportunities for further studies to establish external validity or generalisability in broader contexts, including research with Constructivism-led AT in other countries and with higher numbers of learners. Another avenue could be to study the effects of Constructivism-led AT on different age groups or to enhance Constructivism-led AT to accommodate an appropriate Sign Language and study the effects of that enhancement. In addition, the study only focused on mathematics as a subject and it may be useful to study other important subjects, including languages and sciences. Further research opportunities may involve Constructivism-led AT in inclusive classrooms that comprise learners with and without disabilities or only learners with other disabilities such as visual impairments or even multiple disabilities.

Implications or recommendations

The study encourages the Namibian education policy-makers to prioritise ICT facilities in all schools as stated in their vision 2030 mandate. Although the policy promotes the use of ICT in schools and emphasises the pedagogical use of ICT as an integrated tool in teaching and learning, it does not provide a comprehensive plan with specific resources and dates to ensure the implementation and effective use of ICT in the schools (Ngololo et al. 2012). The study provides valuable information to policymakers about how to integrate Constructivism-led AT to benefit learning environments.

For school management and teachers of children who are deaf, the study offers an intervention with potential for improving their teaching and their learners' mathematics achievement. It has been noted that educators and schools often do not recognise how AT may benefit learners with disabilities (Edyburn 2006). School management and teachers should prioritise becoming familiar with technological tools and complementary learning approaches. Specifically, teachers could follow a Constructivist approach to guide AT use in their classrooms where learning is supported by effective pedagogy, and knowledge acquisition occurs through a process of active construction.

Mathematics teachers for the Deaf could also promote activities that allow learners to think, analyse and reflect on their previous knowledge, supported by Constructivism-led AT. It is important that learners are aware of what they are doing and thinking and are able to build upon prior knowledge. Teaching and learning should be an active process and enable learners to self-assess.

The study demonstrated that RT could be useful in a Constructivist mathematics classroom for learners who are deaf and which has the potential improving the learners' mathematics achievement and increase their motivation and confidence. The study recommends that mathematics teachers test and use RT, which is freely available on the internet and can be used offline, embedded in a Constructivist mathematics classroom.

Conclusion

The study's research problem was the lack of prior research on the effects of ATs on mathematics learning in primary education for the Deaf in Namibia. The study gathered and analysed empirical evidence for understanding the effects of Constructivism-led AT on teaching and learning and the mathematics achievement of Grade 3 learners who were deaf. The data analysis from the experiment suggested that the Constructivism-led AT may have had a positive effect on the multiplication and division achievement of the learners. The data analysis from the interviews with teachers provided support for the positive findings from the experiment. Accordingly, the study addressed the research problem and made an original contribution to knowledge about the effects of Constructivism-led AT in education for the Deaf in Namibia. This informs Namibian teaching and provides guidance for Namibian special schools and educators.

In addition, the study provided learning theory, and AT reviews and selection and demonstrated how a pragmatist epistemology can be applied through an experiment and interviews to gain practical and academic insight into the effects of Constructivism-led AT for the deaf.

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Competing interests

The authors have declared that no competing interests exist.

Authors' contributions

G.H. was the project supervisor and made a substantial contribution to the conception and design of the project. L.A. conducted all of the empirical work, including the experiments and interviews. L.A. wrote all of the initial drafts of the manuscript, including the analysis and interpretation of the data, and G.H. critically revised the drafts for important intellectual content. G.H. and L.A. approved the final version to be published.

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Data availability statement

The anonymised data that support the findings of this study are available from the corresponding author, upon reasonable request.

Disclaimer

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