Constructivist Assistive Technology in a Mathematics Classroom for the Deaf: Going Digital at a Rural Namibian Primary School

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ABSTRACT

Within the context of almost nine million children with hearing disabilities in Sub-Saharan Africa, their education is an important topic. The problem was the lack of conclusive research about the effects of digital assistive technologies for educating deaf learners in Sub-Saharan African countries, such as Namibia. The question was could a digital assistive technology improve the mathematics achievement of deaf children? The research objective was to gather scientific evidence by conducting a quantitative experiment with constructivist digital assistive technology and qualitative interviews with the teachers involved. The findings from the experiment suggest that the constructivist digital assistive technology may have had a positive effect on the mathematics achievement of the learners, which was supported by the findings from the interviews. This makes an original contribution to the domain and offers an intervention that was feasible, practical and potentially effective for improving the teaching and learning of mathematics for deaf learners.

CCS CONCEPTS

• CCS → Applied computing → Education → Computer-assisted instruction

KEYWORDS

Constructivism, Constructivist assistive technology, Deaf learners, Digital assistive technology, Experiment, Hearing disability, Interviews, Mathematics education, Namibia, Primary school education, Sub-Saharan Africa, Teaching and learning

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1 Introduction

Generally, people with disabilities face many challenges [34], especially in relation to social identity and education [29]. Children with disabilities should have the same access to education as non-disabled children [12], so that they can support themselves and contribute to society once they are adults.

The study focuses on children with hearing disabilities, which is significant since deafness or partial deafness is an acknowledged disability affecting approximately five percent of the global population or, in 2018, about four hundred and sixty million people with thirty four million of these being children [76]. Of these children, almost nine million are in Sub-Saharan Africa, which includes the country of Namibia [77].

Deaf learners face particular challenges, which often includes growing up in a family that is not competent in sign language [4,44]. 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 in relation to sign language [75]. Their challenges can result in cognitive deficits that negatively impact academic achievement [33,44] and it has been reported, based on data analyzed over the last three decades, that deaf and hard-of-hearing learners generally lag behind their hearing peers in academic achievement [59].

A prominent and promising approach for addressing the many challenges experienced by people with disabilities and deaf learners' academic achievement is assistive technology, especially digital assistive technologies. These assistive technologies have been widely used by service providers, educators and often in special education [7]. Some instances of assistive technology have been shown to enhance and improve the functional capabilities of students with various disabilities [60] and provide them with opportunities to be independent, gain relevant experience and have prospects similar to learners that are not disabled [32,78]. For example, with reference to deaf learners, one study reported that using animated sign language through the video presentation of a person or a computer avatar provided more lifelike signaling and sped up the teaching process [75]. It has also been stressed that assistive technology should be used as early as possible to improve learning [32].

However, assistive technology alone is not a panacea for teaching learners that have disabilities, since there are many reports of ineffective assistive technology usage [1,9,30,31,69]. Instead, the literature indicates that assistive technology should be implemented in conjunction with a complementary learning theory for improved chances of success [18,27,39].

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 [22]. Thus, teachers should be an indispensable part of teaching and learning with assistive technology and the implementation of any complementary teaching theory [48,54].

Within the aforementioned context, the study focuses on mathematics education since mathematics is needed everywhere in the world and deaf learners need mathematics just as much as other learners [2,17]. Over the years, many efforts have been made to improve mathematics education generally [43]. 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 Kindergarten [41].

The researcher was a citizen of Namibia and, therefore, focused the study in the Namibian context. Furthermore, Namibia has been committed to providing equal education opportunities to disabled learners under the United Nations (UN) Convention on the Rights of the Child (1989) [58], which includes providing support and even assistive devices to children with disabilities [53,57]. It has also been reported that disabled people have the right to affordable assistive technologies and the provision of such assistive technologies is a national and international responsibility [8].

However, according to the researcher's general knowledge of the schools for the deaf in Namibia, there appeared to be no digital assistive technologies for deaf learners in primary or secondary schools throughout Namibia [13]. This was the real-world problem identified by the study. Essentially, given the potential benefits of assistive technology and the learning challenges that are often experienced by deaf learners, the absence of digital assistive technologies potentially disadvantages deaf learners.

Following the identified real-world problem, the literature was searched to determine the extent to which the identified real-world problem had been addressed. Searches on Google Scholar using the keywords "assistive technology" and "education" and "deaf" and "Namibia", their combinations and derivatives returned no directly relevant research involving assistive technology in education specifically for the deaf in Namibia. Thus, there was scant scientific evidence about the effects of assistive technology in education specifically for the deaf in Namibia for informing Namibian policy and providing guidance to the Namibian schools, educators and government.

Nevertheless, many studies were returned that had been conducted in developed countries. However, studying the Namibian context was significant because it has substantial and distinctive contextual characteristics [53]. These include resource scarcity, cultural and language differences and varying technology competencies relating to teaching and learning, which place its deaf learners at high risk of low academic achievement [53].

Therefore, the study's research problem was the lack of prior research about the effects of digital assistive technologies for educating deaf learners in Namibia. Consequently, the research objective was to gather scientific evidence about the effects of a digital assistive technology for the deaf, specifically applied to the teaching and learning of mathematics at a rural Namibian special primary school. Accordingly, the study's main research question was, can a digital assistive technology improve the mathematics achievement of deaf children? The sub-questions were:

1. According to the teachers, who are regarded as experts in the selected teaching context, how was their teaching and their students' learning affected by the digital assistive technology?

2. What was the effect of the digital assistive technology on the mathematics achievement of the learners?

The study involved deaf children in grade three and the subject of mathematics in a rural special school in Namibia. The school was selected due to accessibility and its rural, resource-constrained environment, which placed its learners at high risk of low academic achievement. Grade three 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 concepts [62]. In addition, 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.

The paper consists of five sections. Section One introduced the research and clarifies the research problem, objectives and research questions. Section Two presents the literature review and determines what learning theory and assistive technology was appropriate to guide the study. Section Three explains and justifies the research design, which enables the study to answer the research questions. Section Four is the presentation and interpretation of the data. Section Five presents the research conclusions based on the research findings, answers the research question and presents recommendations, the study's limitations and opportunities for future research.

2 Literature Review

2.1 Disabled Learners, Mathematics and Assistive Technologies

Education for disabled learners has many challenges, including teaching and administrative challenges [35]. The challenges found in Sub-Saharan Africa include the physical make-up of the school environments, overcrowded inclusive classrooms, lack of trained staff, lack of teaching and learning facilities and materials, restriction of learners with disabilities from certain subjects in the curriculum and social exclusion [36,49,55,73].

Many studies have been conducted exposing the challenges encountered by special needs children when learning mathematics. In particular, it has been found that deaf learners are not well engaged with mathematical problems due to language difficulties and insufficient reading ability [38,52,70]. In addition, deaf learners have been found to be less exposed to mathematical activities from an early age than hearing learners, which impedes their understanding of mathematical concepts and development of mathematical foundations in their early childhood years [41].

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 [22,67], negative results [1,40] and mixed results [26,37]. 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 imperative [18,27,39]. The next sub-section presents prominent learning theories to guide the use of assistive technology in the study.

2.2 Prominent Learning Theories in Education: Review and Selection

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 [24,46]. Behaviorism may not be ideal for mathematics learning because learners in behaviorist learning environments are mostly passive and they become active only by reacting to stimuli. Some of these criticisms of behaviorism have been addressed by cognitivism. Cognitivism focuses on the mental structures of learning and gives the mind primacy in the creation of meaning [3]. However, cognitivism has been criticized for not including the creation of meaning through social and individual experiences. In contrast, connectivism is a contemporary learning theory established mainly for e-learning [28] where learning could be achieved through networking in a digital environment. Similarly, connectivism does not focus on knowledge development as a learner's interacts socially.

Constructivism, in comparison, advocates that learners construct knowledge and meaning in their minds, but based on their interpretations of their experiences of the world. In the 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 [66,68].

Furthermore, constructivism has been seen as a necessity in special education [14,23]. 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 skills [11,45,47]. Therefore, constructivism provides an appropriate theoretical basis for guiding the use of the assistive technology in the study and creating a learning environment that is active, learner-centered, participatory and knowledge is constructed from social and individual experiences. Importantly, implementing constructivism with the selected digital assistive technology was conceptualized as constructivist assistive technology, and implemented and analyzed as a single concept in the study.

2.3 Digital Assistive Technology: Review and Selection

The researcher scrutinized the literature for mathematics software applications or assistive technology in similar research contexts and searched the general internet for applicable 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, 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 [20]. In the study, the main evaluation criteria for the mathematics software applications were the study's research objective and their suitability for a constructivist classroom. Subordinate evaluation criteria included whether Namibian sign language was supported, which student grades were supported, what mathematics concepts were supported, its assessment features, tutorial features, learning features, video tutorials, selectable levels of difficulty, timed exercises, printable reports after each session, its usage costs, its availability, the installation options, the operating system required and the hardware requirements.

After considering all the criteria for each software application, the following candidates were rejected as summarized next. Signing Math Dictionary offers signing in American Signed Language (ASL) and Signed English (SE), however, Namibian deaf learners only understand Namibian Signed Language (NSL). In addition, Signing Math Dictionary is only a signing dictionary of mathematics terms, did not have any exercise features and had 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 are not freely available and had features similar to the other applications evaluated. Microsoft Mathematics was not selected because it is more applicable to higher-level grades such as grade

8 to 12. The Geometer's Sketchpad was not selected because it offered mostly geometry-based tutorials.

Out of all the applications evaluated, RekenTest (RT) [63] was the most suitable for achieving the study's research objective and enabling a constructivist classroom. This was evident in its extensive design and potential to support most of principles of constructivism in a classroom [6,50]. Thus, RT supported the study's conceptualization of constructivist assistive technology and enabled its implementation in the study.

In addition, RT was designed to adapt itself to a specific student, based on the student's individual learning. RT was developed for both learners and teachers to make teaching and learning effective in mathematics. RT enables learners to practice, analyze and test their arithmetic skills and offers problems ranging from the easy to difficult. Learners are also offered a progress report after each session. Furthermore, RT provides arithmetic problems for primary school grades and it matches well the curriculum content of the grade three junior primary phase syllabus in Namibia. RT also has the potential to foster a learner-centered approach by allowing learners to investigate the concepts provided by the software through exploration and discovery. Apart from supporting a learner-centered environment, RT is user friendly and its interface is easy to use and straightforward for learners, which is motivating and encourages learners to learn mathematics concepts independently and at their own pace.

3 Research Methodology

3.1 Philosophy, Methodological Choice and Research Strategy

The study was based on the philosophical position of pragmatism, where a researcher chooses research strategies, methods and techniques that are most suited to answer the research questions and address the research problem [16]. The pragmatist epistemology focuses on generating knowledge through research strategies and methods most appropriate to answer a study's research questions. Different research strategies and methods produce different types of data that require specific analysis procedures for understanding, from the method's unique perspective, about those aspects of the world. The pragmatist epistemology matches the unique perspective of a research strategy and method appropriately to a research question to create the required knowledge.

Methodological choice follows from research philosophy [64]. To answer the main research question required two types of data. Research sub-question one required the study to collect and analyze qualitative data from teachers and research sub-question two required the study to collect and analyze quantitative data on the mathematics achievement of the learners. The study's methodological choice was mixed methods [25,74].

Consistent with the study's methodological choice was the study's research strategy. This comprised an interview survey strategy [51] with teachers, who were regarded as experts in the selected teaching context, and an experiment [65] involving experimental groups of deaf learners who used constructivist assistive technology, control groups of deaf learners who did not use constructivist assistive technology and pre- and post-tests to measure the effect of the constructivist assistive technology. This mixed methods strategy was sequential mixed methods where the researcher expanded on the findings from the teacher interview survey with the findings from the experiment. The experiment was conducted first only so that the teachers had the experience of teaching with the constructivist assistive technology before the interviews were conducted.

3.2 Sampling

The special school was a small school and the number of students in each grade was small with grade three having eight children only. Using small numbers in similar types of research has been done [19,42,79] and still provided valuable insights and contributions to the domain.

Random assignment was used to allocate the learners into the experimental or control group. Random assignment ensured that each learner had an equal chance of being assigned to either group and distributed any confounding variables among the groups equally, such as gender, mathematics aptitude and health, because these could potentially influence the effect of the independent variable on the dependent variable, cause errors and biases and ruin the experiment [65].

Random assignment ensured that both groups were comparable, that all these variables were controlled and mitigated several threats to the internal validity of the study, such as history, maturation, main testing, instrumentation, selection bias and statistical regression effects [65].

Following the experiment, interviews were conducted with the three teachers that were involved with the children throughout the study. Such an approach to sampling is usual for qualitative research, where participants were purposefully selected to answer the research question [16]. Notably, quantity of interviews does 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 analyzed [51].

3.3 The Experiment's Data Collection Instruments

For the experiment, the data collection instruments were a consequence of the design of the experiment. The experiment was designed over two weeks, where the first week focused on addition and subtraction only, called Phase One, and the second week multiplication and division only, called Phase Two. Each weekday during both phases, in the afternoons from 2:30pm to 3:10am, 40 minutes each day, the experimental and control groups would attend separate classrooms for the purposes of the study. The reason for conducting two phases was primarily to address the ethical issue of withholding benefits of using the constructivist assistive technology from learners in the control group [65] and to remove social threats to validity [21]. Thus, the learners that were randomly assigned to the experimental group in Phase One become the control group in Phase Two and the learners randomly assigned to the control group in Phase One become the experimental group in Phase Two. The result was that all learners experienced the constructivist assistive technology during the study.

Directly before Phase One began, two different pre-tests, called Pre-test One and Pre-test Two, were administered to both groups together on the same day. Pre-test One included addition, subtraction only, and Pre-test Two included multiplication and division only. The purpose of the pre-tests was to measure the mathematics achievement of the learners before the experiment began. Then, on the last day of the first week or Phase One, both groups wrote Post-test One, which corresponded to Pre-test One and included addition and subtraction only. Finally, on the last day of the second week or Phase Two, both groups wrote Post-test Two, which corresponded to Pre-test Two and included multiplication and division only. The pre- and post-tests were the data collection instruments. The purpose of the post-tests was to measure the mathematics achievement of the learners after the experiment was conducted and to test any potential cause and effect.

For each phase of the experiment, the questions in the post-test and its corresponding pre-test were the same with the exception that the specific numbers were changed. This ensured that the identical mathematical concepts were being tested, the learners were required to apply the necessary mathematics reasoning and the learners could not use memory and recall based on the pre-tests [10]. Each pre- and post-test comprised ten items only since the learners were in grade three and the mathematical 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 and aligned to the objectives and specifications of the curriculum standard for junior primary phase in Namibia [56] as well as grade three mathematics textbooks. This was to ensure that the test items accurately measured the required knowledge and skills of the learners, which promoted validity. For reliability, the study's pre- and post-tests were measured using Cohen's Kappa, which is a measure of rating agreement that corrects for chance agreement [5]. 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".

On all the tests, both raters were in complete agreement on what was appropriate, not appropriate and how to change the not appropriate items. On the addition and subtraction pre-test and corresponding post-test, both raters agreed that 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.

In addition to the mathematics content that was required to be covered during each day of the study, the teachers in the experimental groups were required to conduct the experimental classes in accordance with eighteen constructivist principles [6,50]. Before the study commenced, the researcher met with all the teachers involved, provided training on RT and explained how each of the constructivist principles should be applied during the experimental group classes with RT.

3.4 Ethics

Ethical clearance was required from the University of South Africa (Unisa) in order to carry out the research. The ethical clearance required permission firstly 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 Namibia. Thereafter, ethical clearance was required from the Unisa School of Computing before any data could be collected. Then, each teacher and parent/guardian of the children, since the grade three children participating in the study were below the age of eighteen, was required to provide informed consent before the study began. To ensure confidentiality and anonymity, the names of the participants and school are not revealed in any part of this paper. In addition, respondents' participation was voluntary and respondents were allowed to withdraw from the study.

4 Discussion of Results

4.1 The Experiment

The experiment began on 9 November 2018 and finished on 22 November 2018. Once concluded, the results of the pre- and post-tests were analyzed using t-tests [71] 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 [61]. In addition, 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 scores for the Phase Two experimental group and the post-test scores for the Phase One control group and Phase Two control group. 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 ($p>0.05$).

The first t-test, an independent samples t-test, was done on the pre-tests only were completed to determine if there was any significant difference between the experimental and control groups at the start. Pre-test One ($p>0.05$) and Pre-test Two ($p>0.05$) indicated that there was no significant difference between the groups at this stage and no group began with a significant advantage over the other.

A similar independent samples t-test was done 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 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.

In addition, paired samples t-tests were done for each group between their pre- and post-test scores for each phase. All groups showed $p>0.05$, so that there was no statistically significant change over the time of the study. However, these tests do not measure the effect of the constructivist assistive technology on the mathematics achievement between the groups.

To test the effect of the effect of the 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. For the addition and subtraction phase, there was no statistically significant difference ($p>0.05$) between the control and experimental group in their changed scores. However, for the multiplication and division phase, there was a statistically significant difference ($p<0.05$). This suggests that there was a statistically significant effect of the constructivist assistive technology on the multiplication and division achievement of the learners.

This section answered research sub-question two, and, while these tests suggest that the constructivist assistive technology may have an effect on the mathematics 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

4.2 The Interviews

The teacher interviews occurred after the experiment, on 23 November 2018. The interviews were conducted with three teachers. The first was with the math teacher who taught the addition and subtraction experimental class and the multiplication and division control class. The second was with the math teacher who taught the addition and subtraction control class and the multiplication and division experimental class. The third interview was with another math teacher who was also deaf. This teacher did not teach during the study, but only observed during both experimental classes and, on a few occasions, observed the control classes. During this interview, because the teacher was deaf, one of the other math teachers interpreted for the researcher. The interviews were voice recorded, transcribed and analyzed using Atlas.ti.

The data analysis proceeded with qualitative data coding [51], which is an analytical process to reduce and rearrange the large volume of words into an integrated conceptual model for meaningful insight and conclusions [65]. 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 recognizable themes in the text. Once initial codes have been assigned throughout the text, the process of focused coding proceeds, which is the process of selecting the most frequent or prominent initial codes for arranging, organizing and integrating the data. Thereafter, theoretical coding begins to develop abstract categories from the groups of closely related focused codes.

Theoretical coding also aims to specify relationships between developed categories to form a coherent and integrated theory so that the researcher can draw meaningful conclusions from the data [15,72]. Importantly, memos are critical throughout the data analysis processes to further develop the researcher's analytical insights from the data [15]. Memos are typically informal and spontaneous analytical notes written by the researcher to show what the researcher understands about the data.

Following these qualitative analytical processes, the emergent categories that related to the children's learning with the constructivist assistive technology were collaborating, cooperating, exploring, self-assessing, learning from errors, seeking knowledge independently, self-regulating, self-reflecting, metacognitive thinking and being self-aware. Figure 1 (see next page) provides a visual representation of these conceptual categories and arranges them in relation to group and/or individual learning orientation.

To elaborate, the constructivist assistive technology created a learning environment where the teachers became facilitators and guides instead of instructors. The teachers found this role beneficial for teaching and the children's learning. Furthermore, the constructivist assistive technology formed a learner-centered environment and the children were able to learn in groups by collaborating and cooperating to solve problems on RT. In addition, with RT, 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 RT 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 behavior through individualized selection of problems and the immediate feedback given, which supported self-regulating, self-reflecting, metacognitive thinking and being self-aware.

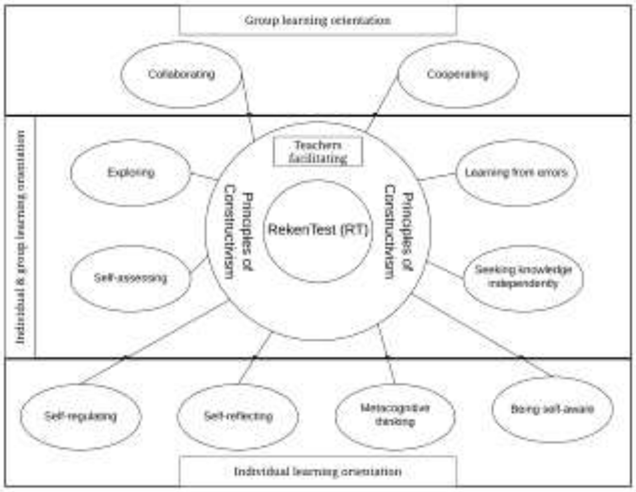

Figure 1: Learning with the constructivist assistive technology

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.

The teachers involved also provided constructive comments for potential improvements, especially for deaf learners who are required to first learn sign language before learning subjects at school and cannot use spoken language for mathematical processes like counting, which is not an obstacle experienced by non-disabled learners. As such, the teachers recommended that RT 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.

This section answers research sub-question one and provides support for the findings from the pre- and post-tests analyses. Given the responses from the teachers, it is plausible that the constructivist assistive technology could have a positive effect on the mathematics achievement of the learners.

5 Conclusions

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 digital intervention may be feasible, practical and effective in such environments. This answers the main research question. Importantly, both the digital assistive technology and the learning theory should be compatible and implemented as a single intervention for better chances at success.

This paper makes an original contribution to the body of knowledge with knowledge produced from a pragmatist epistemology about the effects of constructivist assistive technology for the deaf, using an experiment and interview research strategies. For schools and teachers that teach deaf children, the paper offers an intervention with potential for improving their teaching and their learners' mathematics achievement. The evidence in the study could also inform policy and providing guidance to schools, educators and government. It is recommended that any use of RT be embedded in the eighteen principles of constructivism referred to in this paper for success.

However, the study has 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 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.

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