African Educational Research Journal
Vol. 9(4), pp. 945-955, December 2021
DOI: 10.30918/AERJ.94.21.151
ISSN: 2354-2160
Full Length Research Paper

Visually impaired student-teachers' knowledge and use of basic assistive technology tools for mathematics

Clement Ayarebilla Ali

Department of Basic Education, University of Education, Winneba, Ghana.

Accepted 2 December, 2021

ABSTRACT

Studies show that assistive technology tools have provided opportunities for the visually impaired in some developed countries to pursue mathematics programmes and foster inclusive education. However, their counterparts in developing countries sparingly participate in any mathematical activity due to low knowledge and use of these tools. The main purpose of this study was to expose student-teachers with visual impairments to basic assistive technology tools. The knowledge and use of the tools helped to convert, convey and interpret basic mathematical equations. The design was a case study involving five student-teachers who were admitted to the Department of Basic Education, University of Education, Winneba to pursue a Post Diploma in Mathematics programme. A semi-structured interview guide was used to collect the data whose items contained tools for general administration, additional support, STEM, mathematics instruction, polynomials and assessment. These served as the cases of the study and data analysis. The analysis was undertaken in two stages. The first stage explored their knowledge and use of the assistive technology tools. The second stage analysed transcriptions of statements. The two stages helped to corroborate the findings. To ensure the validity and reliability of the findings, the interview guide was validated by post-graduate students of the Department of Special Education and Basic Education. The findings showed that the student-teachers had little knowledge and use of the basic assistive technology tools. However, they were still desirous to learn and use the basic assistive technology tools for mathematics teaching and learning. It was therefore recommended that stakeholders make available and accessible common basic assistive technology tools to schools, and restructure the mathematics curriculum to suit the integration of assistive technology tools.

Keywords: Assistive technology tools, visually impaired, mathematics education, STEM, student-teachers with visual impairments.

E-mail: ayarebilla@yahoo.com.

INTRODUCTION

Research (Allyn, 2002; Mani et al., 2005; Sawhney, 2014) has discussed many visually impaired mathematicians who have made enormous contributions to assistive technology tools. Notably amongst these are Louis Braille who developed the Braille, Abraham Nemeth who developed the Nemeth/standard Braille, Leonhard Euler who produced Braille manipulatives, Nicholas Saunderson who developed Braille algorithms, Lev Semenovich Pontryagin who organized Braille sets, Louis Antoine who developed Braille topology, Emmanuel Giroux who developed Braille geometry, Lawrence Baggett who developed Braille algebra, Norberto Salinas who invented Braille picture translators, and Zachary J. Battles who incorporated mathematics into the Braille technology.

The original Nemeth had six-dotted Braille codes comprising numbers, symbols and notations intended for the teaching and learning of science, mathematics and technology (National Braille Association, 1987; Allyn, 2002; Mani, et al., 2005; Maddox, 2007; Sawhney, 2014; Braille Authority of North America, 2016). However, the same notations, symbols, operations and numbers (e.g. $a = 1$, $b = 2$, $c = 3$, etc.) were used for both numerals and alphabets. Salinas and John Gardner therefore jointly developed the GS8 to add two dots principally reserved for the teaching and learning of science, technology and mathematics. Some of the technologies in G8 are JAWS to translate text to speech, TRIANGLE to convert LATEX to GS8 codes, and AsTeR to translate TEX to symbols, notations and operations.

Despite these noble inventions, studies (National Braille Association, 1987; Maddox, 2007; McDermott-Wells, 2015) show that the visually impaired still lack access and knowledge of assistive technology tools to participate in school mathematics. For instance, Nemeth Braille is still the only popular tool and very expensive in developing countries.

Another problem is the lack of knowledge and skills in recognizing and cognizing the basic mathematical symbols, notations, symbols and equations of the assistive technology tools. Various studies (Kohanová and Spagnolo, 2006; Maddox, 2007; American Federation for the Blind, 2011; McDermott-Wells, 2015) reveal that the visually impaired hardly experience scientific, mathematical and technological civilizations and innovations in the classroom. They barely encounter and use these technologies embedded in the operations of G8 structures that can foster representations and cognition in numerals and arithmetic operations. This study therefore aimed at employing the universal design for instruction to describe and use the basic assistive technology tools for the visually impaired.

Theory of universal design for instruction

Universal Design for Instruction (UDI) is the practice of embedding and planning a mathematics curriculum to embrace all categories of students on a variety of instructional strategies with digital technology (DeCoste, 2004; Kohanová and Spagnolo, 2006; McGuire and Scott, 2006). This theoretical approach to teaching and learning mathematics ensures proactive design and use of inclusive instructional strategies to benefit the socially excluded in school administration, classroom management and classroom pedagogies. This ensures an inclusive classroom for the diversity of ethnic, economic and language; bridges the special learning needs of mobility, vision, hearing, language, cognitive processing and emotions; provides methodological strategies for schools, learners and instructional materials, and supports learner differences, learning strengths and educational standards.

Here again, UDI properly conceptualizes the teaching and learning of mathematics for the visually impaired with assistive technology tools. The assistive technology tools are acquired commercially, modified and customized to increase, maintain, and improve functional capabilities of the socially disadvantaged. This spans from creating knowledge of the Nemeth Braille to addressing cost, accessibility, fairness, equality, equity and social inclusiveness in the classroom environments (DeCoste, 2004; Beal, and Shaw, 2009; McDermott-Wells, 2015).

Basic assistive technology tools for mathematics education

The Nemeth Braille (National Braille Association, 1987; Maddox, 2007; McDermott-Wells, 2015) is the basic mathematics assistive technology tool for the visually impaired. It embeds with symbols (letters, numbers, punctuations, music notes, and words), notations (composition indicators, termination indicators, mathematical equations, inequality signs and change-of-semantic), and interpreters (cell patterns, cell decoders, voice recorders). The production, manufacturing, education and training of the Nemeth Braille could create jobs not only for the visually impaired but also the sighted (Karshmer et al., 2007; Bell and Mino, 2013). Bell and Mino (2013) estimate that Braille has created about 58% of jobs for Braille readers and 44% for non-Braille readers and that Braille readers earn significantly higher incomes than non-Braille readers in the United States.

In Nemeth Braille, numerous advanced assistive technology softwares convert, transfer and produce documents, graphics and sounds. These include LaTex, MathML, MathType, MathPlayer, Math DAISY, MathJax, Infty Reader, ChaattyInfty, JAWS, and Tactile images. The rest are Crammer Abacus, VP algebra, talking calculator and MS calculator (Karshmer et al., 2007; Sawhney, 2014; McDermott-Wells, 2015; Braille Authority of North America, 2016). Each of these software tools has a specific function designated by the G8 technology. For instance, LaTeX composes mathematics contents, MathML presents mathematics on the web, Math Player converts MathML WebPages, and Math DAISY reads MathPlayer in MS word, MathJax manipulates operations, Infty Reader orgaiizes complicated mathematical expressions/tables/graphs, ChattyInfty provides speech access, JAWS converts dictionary files to screen readers, MathType provides mathematical options, tactile graphics convert graphics, Crammer abacus computes figures, VP algebra performs basic arithmetic operations, IPad talking calculator communicates the operations, and MS standard calculator performs all scientific operations.

Research Conceptual Framework

The conceptual framework for the study was a modified form of UDI A for the applications to teaching and learning. This framework states that the design of teaching and learning must be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design (Burgstahler, 2020).

The framework in Figure 1 provides specific guidance

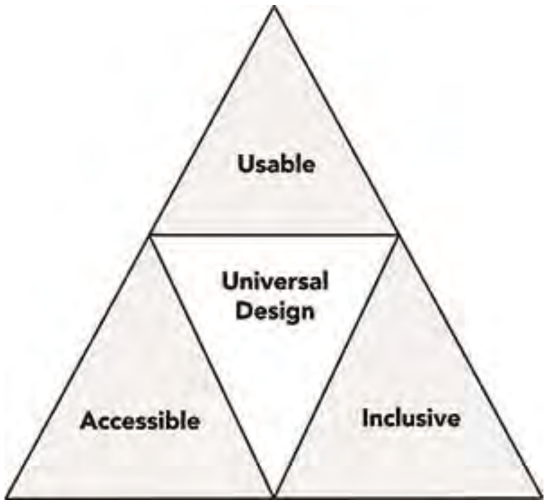


Figure 1. UDI framework for teaching and learning (Burgstahler, 2020).

for designing curricula that enables all individuals to gain knowledge, skills, and enthusiasm for learning. UDL provides rich supports for learning and reduces barriers to the curriculum while maintaining high achievement standards for all (Burgstahler, 2020). The knowledge and skills must not just be beneficial to the student-teachers but the society at large. As teachers in the making, the researcher postulates that such a framework can boost the confidence and competence required to implement STEM courses in general and mathematics areas in particular.

The following research questions were outlined to guide the study:

1. What knowledge do student-teachers with visual impairments have on basic assistive technology tools for STEM education?
2. Which areas of mathematics can student-teachers with visual impairments use the basic assistive technology tools?

Research objectives

Following the research questions, the objectives of this study were:

1. To explore visually impaired student-teachers' knowledge and use of basic assistive technology tools.
2. To assess the areas of mathematics student-teachers can use the basic assistive technology tools

METHODS

The case study design was employed to study the knowledge and areas of use of the basic assistive tools in science, technology, engineering and mathematics (STEM) classroom interactions. This will ensure that all people fully attain the universal education for all children of school-going age (Assistive Technology Industry Association - ATIA, 2004). In this case study, five student-teachers with visual impairments were involved. These five student-teachers were admitted into the university to pursue a programme that contains all the STEM courses. The case study design was appropriate and suitable to target basic characteristics of visually impaired student-teachers of all degrees of vision (partial vision, low vision, partially sighted, blind) who teach in the basic schools in Ghana. The cases were general administrative, additional support, STEM, mathematics instruction, polynomial equations and mathematics assessment.

The instrument of data collection was the semi-structured interview guide which was partitioned into the demographic information in addition to the six cases of the design. These instruments allowed the student-teachers to make choices and explain the reasons for the choices they have made on the tools. The results were analyzed in two stages. In the first level, the researcher showcased results on the knowledge of the various assistive technology tools as structured into general administrative tools, accommodation supports, STEM education, mathematics instruction, sample mathematics equations, and mathematics assessment. The mean and standard deviation were used to assess their knowledge at this level. The second stage transcribed the open discussions with the respondent on the same thematic areas of the cases and assigned reasons to the statements. This was to corroborate the discussions on the knowledge and use of basic assistive technology tools in the first stage. The second also helped to understand the reasons for the knowledge of tools in the first stage (Edwards et al., 2006; Ferrell et al., 2006).

The validity and reliability of the instruments and the findings were addressed. To address the validity of the findings, the interview guide was validated by post-graduate students of the Department of Special Education and Basic Education. As part of their studies, this group of students had ever taken at least two courses on disability, equity and social inclusion. This is one of the strong requirements of an undergraduate student-teacher to complete the University of Education, Winneba and be conferred with a degree. To address reliability, Cronbach's alpha coefficient was employed to determine internal consistency, and test-retest reliability was employed to determine stability over time. Cronbach's alpha values of .70 and above imply an acceptable level of internal consistency (Wang et al., 2015).

Ethical concerns include anonymity of participants, treatment of vulnerable populations, lack of informed consent, and benefit versus undue hardship when using people with disabilities as research participants.

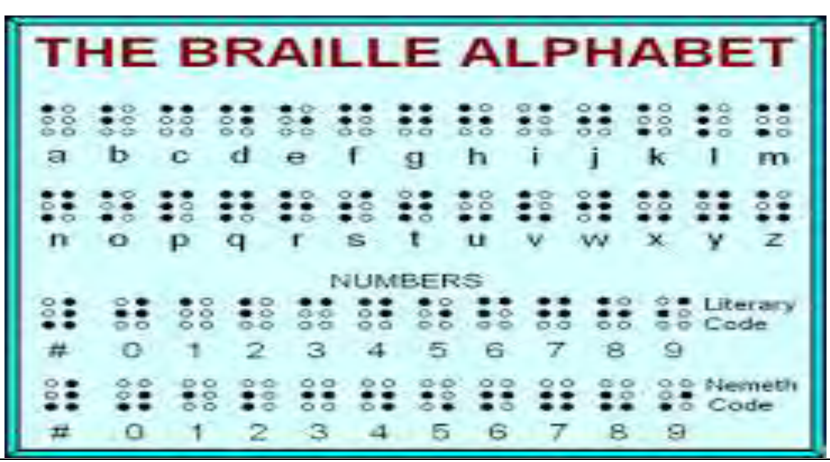
Consequently, the researcher developed a protocol explaining the process that was to be followed should a child with disabilities disclose sensitive or worrying information. Within this context, a referral network was identified, and referral pathways were articulated in a clear plan (Thompson et al., 2020). Having interacted with the research participants for over one year, the researcher had built mutual respect and trust with them. This enabled them to open up to provide the needed information. As a result of the mutual respect and trust, discussions on issues of disability and vulnerability were friendly and they were ensured I would not disclose any information or leak their identity to the public except for research purposes. Having considered their vulnerability, the study was carried out in their usual serene and conducive lecture theatre. So, no hardship was incurred and no benefit was accrued to me as it was carried out within the official time and work in the University.

RESULTS

Research Question 1: What knowledge do student-teachers with visual impairments have on basic assistive technology tools for STEM education?

Tables 1 to 3 were used to answer this research question. The student-teachers were guided to outline the tools. The researcher, on the other handed, acquired the tools for discussions.

Table 1. General administrative assistive technology tools.

Assistive tool	Picture of tool	Knowledge
Braille writer		5.7 (0.27)
Braille notetaker		4.8 (1.01)
Alphanumeric Grid		3.9 (0.26)

Credit: National Braille Association (1987).

Table 2. Additional assistive technology support and accommodation tools.

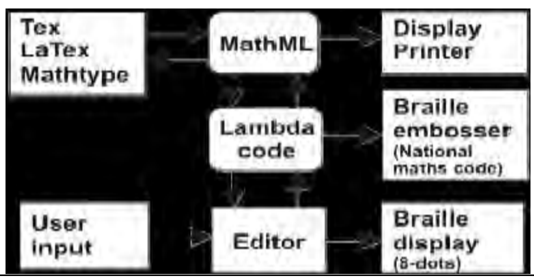
Assistive tool	Picture of tool	Knowledge
Braille scanner		3.2 (1.10)
Braille bookbinders		3.01 (1.02)
Braille Embosser		2.5 (1.02)

Credit: High Tech Center Training Unit (2005).

The different dimensions of general administrative assistive technology tools in this category are Braille writers, voice narrators, screen reading software, talking web browsers, electronic note-takers, electronic typewriters, alphanumeric grid and tactile images. Out of the eight basic tools in this category, only two were sometimes available. All the others had never been accessible to the student-students with visual impairments. This means the typical teacher and administrator will not have the necessary tools to construct mathematical knowledge for student-teachers with visual impairments. The three tools (Marson et al., 2012) in Table 1 are necessary to serve common basic functions of the teachers and/or school administrator. However, in order of knowledge, the Braille 5.7(0.27) serves as the first point of call to technological and typing skills in the school, the Braille notetaker 4.8 (1.01) serves the school register, and the alphanumeric grid 3.9 (0.26) provides the mathematical notation and symbols. One other administrative tool for the visually impaired is the voice narrator. The voice narrator assists teachers and administrators to create enabling environment not only for good interaction but also for the pedagogical dissemination of voice and speech during teaching and learning in the technology-oriented mathematics classroom. This makes the classroom more accommodating, visually friendly and consistent with international norms for the visually disadvantaged.

The figures in Table 2 highlights the additional support and accommodation assistive technology tools the visually impaired can utilize to support them in the mathematics classroom. The many varied support and accommodation assistive technology tools for the visually impaired students are scanner, bookbinder, embosser, talking dictionary, word prediction software, image simplifying software, text-to-Braille translation software, embosser, and colour copier. Here again, only three tools (word prediction, text-to-Braille translator and image

Table 3. Science, technology and mathematics assistive tools.

Assistive tool	Picture of tool	Knowledge
Braille phones		5.2 (0.05)
Braille calculator		4.9(0.53)
MathType system		2.5 (0.81)

Credit: High Tech Center Training Unit (2005).

simplifier) were scarcely available to the visually impaired. These were Braille scanner (3.2, 1.01), Braille bookbinders (3.10, 1.02) and Braille embossers (2.5, 1.02). Two were sometimes available, four were known but not just available and over half were never known. This suggests that student-teachers with visual impairments still experience weak knowledge on support and accommodation systems for STEM learning (Sawhney, 2014). However, support and accommodation systems (DeCoste, 2004) include pencils, laminated alphabet guides, physical baselines, and clipboard keepers. These items add a lot of boost to the study of mathematics in particular.

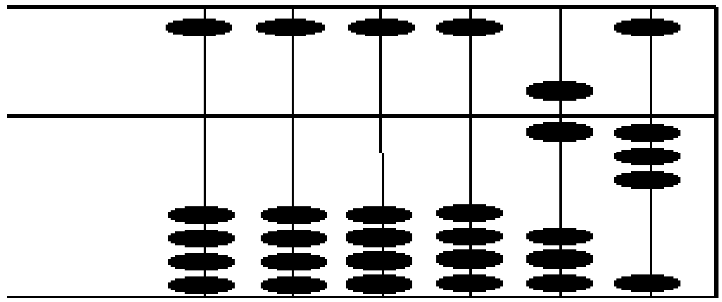
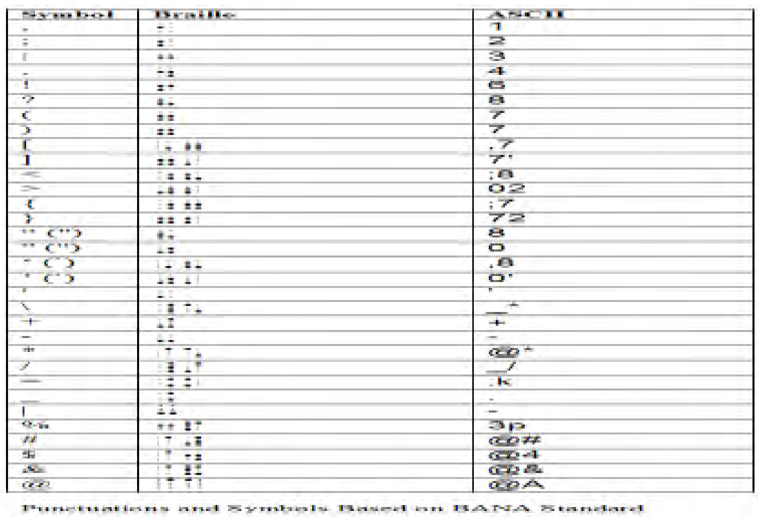
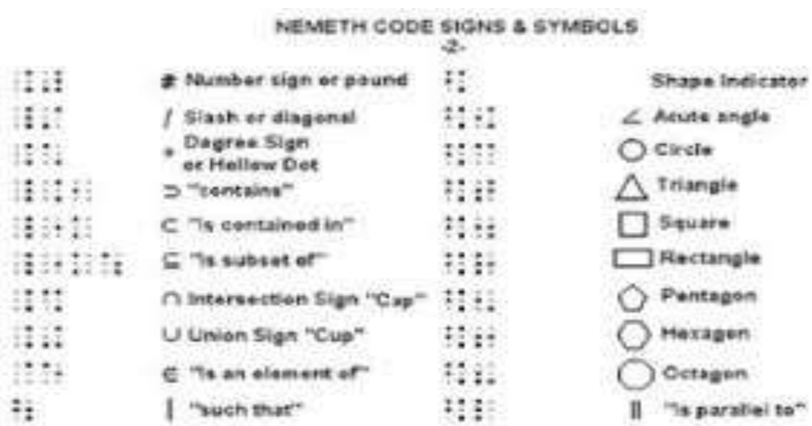
The tools in Table 3 show the assistive technology tools designed to teach and learn all courses related to STEM courses. The different assistive technology tools include Braille phones, Braille calculators, MathType system, Braille compasses, talking GPS, manipulatives, adapted games, and Braille blocks (Maddox, 2007). It is worrying to note that out of the eight basic STEM tools we sampled, only three were sometimes availably known to the student-teachers with visual impairments, and all the others have never been encountered. The Braille phone (5.2, 0.05) is used for interactions, Braille calculator (4.9, 0.53) for all manipulations and MathType system (2.5, 0.81) for the procession of all scientific information. All assistive technology tools in this category help student-teachers to read texts, symbols, notations, equations and solutions from the computer. It is therefore important that student-teachers in this category know and be able to use them in the study of STEM especially mathematics.

Research Question 2: Which areas of mathematics can student-teachers with visual impairments employ the basic assistive technology tools?

Tables 4 to 6 were used to explore this research question. While the student-teachers discuss the assistive technologies, topics in mathematics and assessment of mathematics outcomes, the researcher gathered and downloaded them for class instruction.

Table 4 displays assistive technology tools for the teaching and learning of mathematics. The Braille abacus is used for counting and place value, place chart for addition and subtraction and Braille shapes for area and relationships among figures. There are many other assistive technology tools for the teaching and learning of

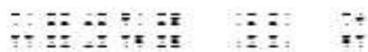
Table 4. Assistive technology tools for mathematics instructions.

Tool	Picture of tool	Area
Braille Abacus		Counting and place value
Braille chart		Addition and subtraction
Braille shapes		Area and relationships

Credit: High Tech Center Training Unit (2005).

mathematics for the visually impaired. However, the researcher sampled Abacuses, Braille charts, Braille shapes, mathematics tiles, and text-to-speech narrators because of their enormous significance in the teaching and learning of STEM courses (Sawhney, 2014). It was equally revealed that about half of these tools never existed and as such they were not accessible to the visually impaired student-teachers. The Abacuses, Braille chart and Braille shape typically represent place values, mathematics operators and basic geometric figures (DeCoste, 2004; Braille Authority of North America, 2016) essential for representations and manipulations of mathematical problems in the classrooms. DeCoste (2004) elaborates more on the number line, mathematics worksheets, magnified worksheets, mathematical facts charts and tape recorders, computer-based calculators,

Table 5. Assistive technology tools for polynomials.

Polynomial	Sample equation	Area
Linear equation	$ay + bx + c = 0$ 	Roots and nature of parabola
Simultaneous equations	$ax + by = e$ $cx + dy = f$ 	Elimination Substitution Graphical
System of equations	$a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n = b_1$ $\ldots$ $a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n = b_2$ $\ldots$ $a_{m1}x_1 + a_{m2}x_2 + \ldots + a_{mn}x_n = b_m$ 	Coefficients Determinants Inverses
Quadratic equation	$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ 	Roots Discriminants

Credit: High Tech Center Training Unit (2005).

mathpad software, instructional software, scientific notebook and graphing calculator that equip visually impaired student-teachers to conceptualize mathematical statements and solve mathematical problems.

The sample polynomial equations in Table 5 show the assistive technology tools student-teachers with visual impairments can use to write and solve polynomial problems. Out of the several polynomials, it was revealed that no single visually impaired student-teacher had ever used these equations in the mathematics classroom. This revelation indicates that even though some visually impaired student-teachers have minimal knowledge and awareness of general assistive technology tools, they have never accessed assistive mathematics tools. However, the Braille Authority of North America (2016) points to the fact that these notations, symbols, expressions, fractions and formulae exist in the Nemeth Code. There is therefore the need for policymakers and other stakeholders to carve out policies and programmes aimed at training and resourcing the visually impaired to employ the tools in solving mathematics problems.

Table 6 represents the assistive technology tools for mathematics assessment. Some of the tools needed JAWS, DAISY and Braille graphic display sampled for managing assessments, practicals and examinations. It was revealed that only two were scarcely available but were never used by the student-teachers with visual impairments. It must be noted that elsewhere, the

Table 6. Assistive technology tools for mathematics assessment.

Tool	Picture of tool	Use of tool
Job Access with Speech (JAWS)		Speech
Braille graphic display		Displays
Audio DAISY		Hearing

Credit: High Tech Center Training Unit (2005).

commonest assessment tools are portable word processors, keyguards, screen magnifiers, mouthsticks, headsticks, talking word processors and voice recognition software (DeCoste, 2004). It is therefore incumbent on stakeholders to make these tools accessible and available for assessing and evaluating the works of the visually impaired in mathematics.

DISCUSSION

On the open discussion of issues of improving quality and accessibility of assistive technology tools, the following conversation was transcribed:

Researcher: Apart from the assistive tools outline in (I) above, mention any other tool(s) you use for General Academic and Administrative Work in your school.
Participant 1: *Laptops and computers*.
Researcher: Apart from the assistive tools outline in (II) above, mention any other tool(s) you use for any STEM course in your school.
Participant 2: *No idea. I only know laptops and computers*.
Researcher: Apart from the assistive tools outline in (III) above, mention any other tool(s) you use for teaching and learning Mathematics in your school.
Participant 3: *Books, chalk, crayon and pencils. We don't teach mathematics in our schools. So we do not use laptops and computers for mathematics*. *We only use laptops and computers for typing letters and playing games*.
Researcher: Apart from the assistive tools outline in (IV) above, mention any other tool(s) you use for supporting the visually impaired in your school.
Participant 4: *Government and other NGOs support the special schools with sticks and wheelchairs. We also support each other during teaching and learning the other subjects we teach and learn. But we as blind people don't teach mathematics. So we don't have supports to talk about in mathematics*.
Researcher: How do you intend to improve upon the quality and quantity of assistive technology tools in your school?
Participant 5: *I hope that there is something like a projector with a computer to help teachers and pupils. We need many tools to teach mathematics but Sir, we have not even heard of the tools you have mentioned. So it will be very difficult for me to talk of assisting pupils when I don't personally even know them.*
Participant 1 and 2: *However, to help me improve upon computer technology, I have installed JAWS on my laptop and TTS on my mobile phone but I don't use them to teach mathematics. The reason is that I have no knowledge that these tools can be used to teach and learn mathematics. So, you people should try to help us acquire more of those tools for the teaching and learning of mathematics*.
Participants 3, 4 and 5: *Also, we do not write Basic Education Certificate Examinations in mathematics in Ghana. The reason is that we don't teach mathematics at the primary and junior high school levels. If the curriculum had provided for the examinations of mathematics for the visually impaired at the lower levels of education, we would have tried to learn them and teach our students. If the government introduces mathematics in the BECE*

examinations, it will compel us to learn those tools. Otherwise, when you learn them what are going to do with that knowledge?

The conversation with the five participants clearly shows that Nemeth Braille adequately addresses cost, accessibility, fairness, equality, equity and social inclusiveness in the classroom environments (DeCoste, 2004; McDermott-Wells, 2015). However, despite the availability of numerous basic assistive technology software that convert, transfer and produce documents, graphics and sounds, as stated by Karshmer et al., (2007), Sawhney (2014), McDermott-Wells (2015) and Braille Authority of North America (2016), the respondents had no idea and could only cite laptops and computers. To make the situation worrisome, the respondent who was a student-teacher alluded that they do not teach mathematics in special schools. There is, therefore, an urgent need to bring to the fore the core issues of inclusion in the modern mathematics classroom.

Also, the most important parts of mathematics being taught and learned in school are polynomial equations and expressions. However, visually impaired student-teachers have minimal knowledge and awareness of general assistive technology tools they can access for teaching and learning mathematics. The Braille Authority of North America (2016) points to the fact that notations, symbols, expressions, fractions and formulae exist in the Nemeth Code and help visually impaired people in mathematics. There is therefore the need to carve out policies and programs aimed at training and equipping the visually impaired to employ the tools in solving mathematics problems.

Again, the conversation summarizes the whole episode of the state of knowledge and use of basic assistive technology tools in developing countries like Ghana. There is no gain repeating the reasons for the abysmally low knowledge and use of these tools. The commonest assessment tools stipulated by DeCoste (2004) for the visually impaired can help measure, assess and evaluate teaching and learning. It is therefore incumbent on stakeholders to make these tools accessible and available for assessing and evaluating the works of the visually impaired in mathematics. The major reason discovered was inadequate availability of the tools and low knowledge of the visually impaired student-teachers in mathematics. We, therefore, advance a few recommendations to ameliorate the plight of the visually impaired student-teachers who wish to pursue mathematics as a profession.

CONCLUSION AND RECOMMENDATIONS

The findings reveal that several assistive technology software are available for the visually impaired to actively participate in mathematics in basic school. However, there is still low knowledge and use of these assistive technology tools for the teaching and learning of mathematics. There is, therefore, the need to improve upon the existing assistive technology tools and encourage the visually impaired to study and teach mathematics in school. This will ensure that UDI enhances lifelong learning and equitable opportunities for their employment and other social engagements (The Royal Blind School, 2011).

Secondly, the findings were limited to assistive technology tools via the Nemeth code and G8 structures. There is therefore the need to employ other tool(s) that expand the mathematics operations, describe mathematical problems in detail and integrate technology tools with mathematics for the visually impaired (The Royal Blind School, 2011).

Again, the research sought to improve knowledge and awareness of assistive technology tools in the basic school. It must be acknowledged that even though such assistance has always been channelled to visually impaired institutions, there should be extensions of these opportunities to all vulnerable and socially disadvantaged groups (Sawhney, 2014).

Finally, it must be acknowledged that the conclusions were not based on the experimental design on either the student-teachers with visual impairments or sighted teachers in the basic school. There is a need to conduct an experimental-control study on the knowledge and skills of all teachers to assess the feasibility of integrating assistive technology into mathematics instruction.

These notwithstanding, it was recommended that stakeholders make available and accessible basic assistive technology tools to schools, and restructure the mathematics curriculum to suit the integration of basic assistive technologies.

Policy recommendation

The findings show that the most important parts of mathematics being taught and learned in school are polynomial equations and expressions. However, visually impaired student-teachers have minimal knowledge and awareness of general assistive technology tools they can access for teaching and learning mathematics (The Braille Authority of North America, 2016). It was therefore recommended that policymakers step up their efforts of acquiring these basic assistive technology tools. This is the surest way curriculum for basic levels of education can attain maximum level inclusivity, equity and integration.

Further research recommendation

The conversation with the five participants clearly shows that Nemeth Braille adequately addresses cost, accessibility, fairness, equality, equity and social inclusiveness (McDermott-Wells, 2015). It was therefore recommended that further research be conducted on the knowledge and use of the Nemeth Braille in place value and basic arithmetic operations.

Declaration of conflicting interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author received no financial support for the research, authorship, and/or publication of this article.

REFERENCES

Allyn, J. (**2002**). The World of Blind Mathematicians. *Notices of the AMS* Volume 49, Number 10, pp1-6.

American Federation for the Blind (**2011**). *What is Braille?* Retrieved July 29, 2016, from http://www.afb.org/section.asp?SectionID =6&TopicID=199.

Assistive Technology Industry Association - ATIA (**2004**). Assistive Technology Outcomes and Benefits. A Joint Publications of ATIA and the Special Education Assistive Technology Center, 1(1): 12-24.

Beal, C. R., and **Shaw**, E. (**2009**). An online math problem solving system for middle school students who are blind. MERLOT Journal of Online Learning and Teaching, 5(4): 1-9.

Bell, E. C., and **Mino**, N. M. (**2013**). Blind and visually impaired adult rehabilitation and employment survey: Final results. The Journal of Blindness Innovation and Research, 1: 12-24.

Braille Authority of North America (**2016**). Guidance for Transcription Using the Nemeth Code within UEB Contexts. New York: Braille Authority of North America.

Burgstahler, S. (**2020**). Universal Design of Instruction (UDI): Definition, Principles, Guidelines, and Examples. U.S.A.: The Center for Universal Design in Education. Retrieved from https://www.washington.edu/doit/universal-design-instruction-udi-definition-principles-guidelines-and-examples.

DeCoste, D.C. (**2004**). A Handbook on Universal Design for Learning and Accessible Technology: Proactive and Accommodative Instructional Strategies for Today's Teachers. Rockville: Montgomery County Public Schools.

Edwards, A. D. N., McCartney, H., and Fogarolo, F. (**2006**). Lambda: A multimodal approach to making mathematics accessible to blind students. *ASSETS 2006*, October 22–25, 2006, Portland, Oregon, USA.

Ferrell, K. A., Buettel, Sebald, A. M., and Pearson, R. (**2006**). American Printing House for the Blind: Mathematics Research Analysis. University of Northern Colorado: National Center on Low-Incidence Disabilities.

High Tech Center Training Unit (**2005**). Overview of Math Accommodations. California Community Colleges: High Tech Center Training Unit.

Karshmer. A., Gupta, G., and Pontelli, E. (**2007**). Mathematics and Accessibility: A Survey. International Conference on Computers Helping People (ICCHP), Springer Verlag, pp. 614-619.

Kohanová, P. I., and **Spagnolo**, F. (**2006**). Teaching mathematics to non-sighted students: with specialization in solid geometry. Comenius University Bratislava: Doctoral Thesis.

Maddox, S. (**2007**). Mathematical equations in Braille. MSOR Connections, 7(2): 1-8.

Mani, M. N. G., Plernchaivanich, A., Ramesh, A. G. R., and Campbell, L. (**2005**). Mathematics Made Easy for Children with Visual Impairment. Philadelphia: International Council for Education of People with Visual Impairment.

Marson, S. M., Harrington, C. F., and Walls, A. (**2012**). Teaching introductory statistics to blind students. Teaching Statistics Trust, 35(1): 21–25.

McDermott-Wells, P. M. (**2015**). Math in the Dark: Tools for Expressing Mathematical Content by Visually Impaired Students. PhD Dissertation: Nova Southeastern University College of Engineering and Computing.

McGuire, J. M., and **Scott**, S. S. (**2006**). Universal Design for Instruction: Extending the Universal Design Paradigm to College Instruction. Journal of Postsecondary Education and Disability Special Issue: Universal Design in Higher Education, 19(2): 124-134.

National Braille Association (**1987**). The Nemeth Braille Code for Mathematics and Science Notation 1972 Revision. Kentucky: American Printing House for the Blind.

Sawhney, K. (**2014**). STEM Access for the Blind and Visually Impaired. ENGR 110-210: Perspectives in Assistive Technology.

The Royal Blind School (**2011**). The Braille Policy. London: Royal Blind School.

Thompson, S., Cannon, M., and Wickenden, M. (**2020**). Exploring Critical Issues in the Ethical Involvement of Children with Disabilities in Evidence Generation and Use, Innocenti Working Paper 2020-04, UNICEF Office of Research–Innocenti, Florence. Retrieved from https://www.unicef-irc.org/publications/pdf/IWP-Working-Paper-ethical-involvement-of-children-with-disabilities-in-evidence-generation.pdf.

Wang, L., Qi, J., and Wang, L. (**2015**). Beliefs of Chinese physical educators on teaching students with disabilities in general physical education classes. Adapted Physical Activity Quarterly, 32: 137-155.

Citation: Ali, C. A. 2021. Visually impaired student-teachers' knowledge and use of basic assistive technology tools for mathematics. African Educational Research Journal, 9(4): 945-955.