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IntelliMath - an accessible automated mathematics tool for the students who are blind

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CONTEXT

In this ever-changing world of technology and innovation it is sad to find out that the students who are blind struggle to study Mathematics mainly because of the inaccessible resources and assistive technologies. The existing tools are not sufficiently intelligent to deliver the correct meaning of a mathematical expression or equation thus causing confusion to the targeted group of students. Hence, the students with vision impairments are reluctant to go towards mathematics and Science, Technology, Engineering and Mathematics (STEM) related subjects.

PURPOSE OR GOAL

The study investigated the challenges faced by the students with vision impairments in studying Mathematics and other STEM- related subjects. Based upon those challenges and the gaps identified, the present study designed and developed an intelligent automated tool – **IntelliMath** that converts the graphical mathematics equations into a meaningful audio which helps the students who are blind to understand and hence solve the mathematics problem efficiently. The study also assessed the impact of IntelliMath tool (validation) and how the tool assisted the students who are blind in overcoming the challenges related to studying mathematics and other STEM subjects.

APPROACH OR METHODOLOGY/METHODS

With the adaptation of mixed- methods the study collected both the quantitative and qualitative data. Quantitative data helped to discover participants responses (scores) in terms of ease of use, the efficacy of the program, motivation, and satisfaction after usage of IntelliMath tool. Qualitative data was analysed using SPSS tool. Qualitative data supplemented the research by finding the participants feelings by an open-ended interview. It was analysed by content analysis, open and axial coding and further creating themes and sub-themes.

ACTUAL OUTCOMES

The outcomes of the study are: (1) The challenges identified which demotivated the students who are blind to study mathematics and STEM subjects, (2) a fully developed automated tool **IntelliMath** which works along with a screen reader to deliver the maths content efficiently, (3) impact of the developed tool on the students with vision impairments which motivated them to study mathematics and STEM subjects.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

In Conclusion, the research has been successful in its purpose with the development of a unique tool **IntelliMath** and its validation. The results of the study infer that the targeted students found IntelliMath tool easy to use and efficient in its purpose. The students were very satisfied in using the tool and got motivated towards studying Mathematics and other STEM related subjects after using the tool.

KEYWORDS: STEM Education for Visually impaired; Engineering Education; STEM with Disability; Students who are blind.

Introduction

STEM has been globally identified as a framework to support the technical education which enhances the prospects for a job seeker and opens a world of opportunities in related areas. Although STEM provides enormous opportunities but at the same time it has huge gaps to cover (Department of Industry, Science and Resources, 2023). Those gaps can be identified mainly in areas like Women in STEM, STEM with Disability and STEM for diverse demographic groups which raises the issues of inequality, accessibility, diversity, gender bias, religion and different income levels (Subcommittee on STEM Education of the Future, 2020; Science & Technology Australia, 2023). While there have been many attempts initiated worldwide to reduce such gaps, this research solved the accessibility problem for the students with disabilities with focus on the students who are blind and struggle in accessing STEM.

Students with vision impairments (SVI) face enormous challenges during their studies and most of them do not complete their tertiary level degrees (Ivey et al., 2012). These challenges become extreme when it comes to studying scientific subjects such as Science and Mathematics because of their inherent complex nature. SVI are the most underprivileged individuals when it comes to studying STEM units/courses because of the visual nature and intricacies involved in them (Jones et al., 2006; Borland & James, 1999). Some of the challenges faced by the targeted students are: accessing technical notations such as scientific equations and formulae; accessing visual resources such as charts, diagrams and graphs (Gardner, 2002; Gould et al., 2009); understanding the visual content which cannot be explained in two dimensions; execution of various experiments which requires visual needs; understanding the STEM subjects by “chalk and talk” methods which involve listening and working out examples on the board along with the teacher (Cryer, 2013).

To overcome the above-mentioned issues, the study has designed and developed an accessible automated tool for students with vision impairments to study Mathematics called IntelliMath. SVI uses screen readers like JAWS (JAWS, 2024) with Mac operating system and NVDA (NV Access, 2024) with windows to study electronic documents which renders the text to speech/audio. IntelliMath reads the tertiary level mathematics correctly using an audio. It is a software plug-in which is designed and tested to get integrated with the NVDA screen reader for the ease of use for the SVI.

Background and Objectives

Literature- Review

The idea of the study emerged after doing extensive research in finding the gaps in STEM education. One of the areas identified was ‘STEM with Disability’. Moon et al. (2012) clearly identified that the SVI do not go towards STEM education because of inaccessibility of the education methods and resources. The disability sector is huge, so after undergoing relative research in the area, the researcher narrowed it down to the disability related to vision impairment. The compelling reason to choose this area is the gap in STEM accessibility for the students with vision impairments.

In the present time of e-learning the common way of studying is through online resources using the electronic documents such as pdf, docx, odt, etc. There are various Assistive technologies which are developed to assist the SVI in studying mathematics, but they fail to deliver the subject intelligently. SVI use braille as a traditional learning platform but it is very cumbersome to use heavy braille books for mathematics. Rapp and Rapp (1992) demonstrated in their study that SVI who use braille participated less in the advanced level mathematics. According to a report, the mechanical aspects of mathematics such as reading the questions, handling cumbersome braille material and management of information created more problems for SVI than understanding the actual concepts of mathematics (Cahill, 1996). Electronic braille displays are used to represent graphical mathematics, but the equipment is very expensive and unaffordable for most of the targeted students. There are audio platforms which were developed in the past and can speak mathematics but are inefficient. They fail to comprehend and speak the complex tertiary level mathematics meaningfully. Research signifies that having a reader or technology to use audio can be very confusing for SVI as they can misinterpret the mathematical expression easily (Rowlett & Rowlett, 2009). Cliffe (2009) highlights that the non-linear and two-dimensional large set of mathematical symbols make the process of conversion even more complex. The efficient system must convert the information from one format to other and conveys the meaning of a visually presented equation and then deliver in a format which is accessible and understandable by the learner (Cryer, 2013).

One of the assistive technologies is the text to speech (TTS) software commonly known as screen readers. There are different screen readers for different operating systems for example NVDA and JAWS for windows and VoiceOver for Mac OS, etc. The screen readers are proficient in reading the textual part of an electronic document but when the cursor points to the scientific/ mathematical equation/formula or graphical part, it either speaks out a garbage value, becomes silent or skips that part. This inconsistency in screen readers cause immense confusion for the SVI and becomes the reason for their frustration and demotivation to continue with the subject. According to the existing literature, there has not been much work done for Audio rendering and the existing work has some limitations. Some tools that have been developed for converting the Latex and MathML notations into an audio are discussed in this section. The tools which were developed and implemented in the past for mathematics were AsTeR (Raman, 1994), MATHSPEAK (Nazemi et al., 2012), i-Math (Wongkia et al., 2012), MathPlayer (Soiffer, 200**7**), AudioMath (Ferreira, & Freitas, 2005). However, they all have significant shortcomings, and mostly outdated, unsupported and cannot be further developed for adding new modules or languages. These tools lack in navigability, coverage of tertiary level mathematics and reading of mathematical expressions intelligently from the web pages or standard electronic documents such as PDF and Word. Specifically, there was no support available for the standalone pdf documents which are the most used as educational resources in today's world (Fichten et al., 2009). The issues mainly narrow down to lack of intelligibility and navigability in the above-mentioned tools.

Research Objectives

The significance of this research is to make the SVI independent in studying tertiary level mathematics which will boost their confidence and skills to get enrolled in STEM courses. With the help of IntelliMath the students will no longer require the help of a reading assistant which is their traditional way of learning. IntelliMath helps in providing a clear conceptual understanding of mathematical content by delivering it in the form of an audio. It will act as a support to the targeted students, and they will be able to study mathematics concepts without anyone’s help. IntelliMath acts like a backbone to the TTS by providing support for the mathematical part.

The main aim of this research is to develop a system which allows access to Science, Technology, Engineering and Mathematics (STEM) courses to students who are blind. The study provides a solution by designing and developing an automated tool which provides accessibility and inclusivity for tertiary level Mathematics to the students with vision impairments.

The specific research aims are:

- to investigate the challenges faced by students who are blind in completing STEM courses.
- to develop an intelligent automated tool that will assist in converting graphical mathematical equations into a meaningful form for students who are blind; and
- to assess the impact of the proposed tool and how this tool assists students who are blind in overcoming challenges related to the study of Mathematics.

Design and Development of IntelliMath

Design

The tool was developed as a plugin to the NVDA (NV Access, 2024) screen reader for the following reasons: the students with vision impairments are comfortable using NVDA screen reader, it is free to download and an open-source software, work with computers using windows operating system which are more affordable than the computers using Mac operating system and normally works well with Pdf, HTML and word documents. The researcher decided to use an existing solution and extending it for the purpose of solving the problem of Mathematics inaccessibility rather than re-inventing the wheel. The next task was to design and model a plugin for NVDA screen reader which could read the maths objects present within the electronic document (pdf) and convert them into meaningful audio. This section discusses the block diagram and process diagram of IntelliMath which describes every element of the design.

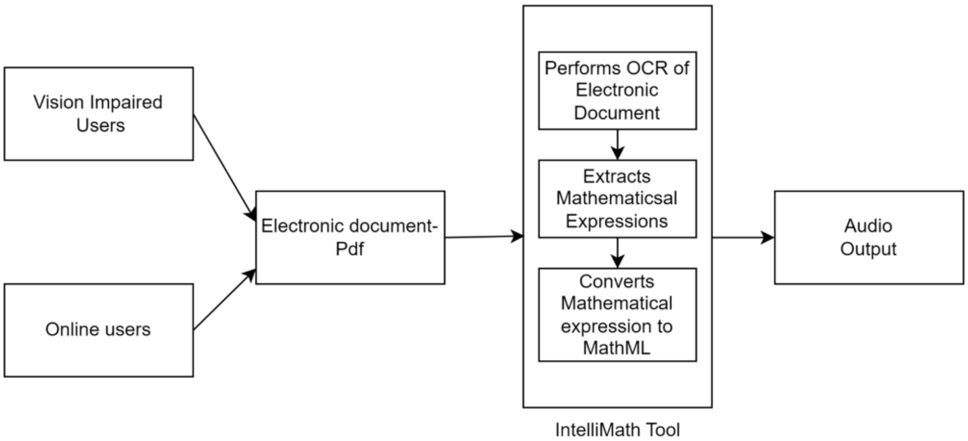

Figure 1: Block diagram of IntelliMath

Figure 1 illustrates the block diagram of the IntelliMath tool. IntelliMath tool is designed and developed to integrate with the screen reader (NVDA) for an audio output of the document with mathematical content. The users can access an electronic document (pdf) from the internet and can read it using the screen reader enabled with IntelliMath plugin. The working of IntelliMath is describes as follows: The pdf document to be read is opened by the screen reader (NVDA). The textual part is normally run by the screen reader but the part with mathematics content is passed onto the IntelliMath. IntelliMath is divided into three parts. The first part performs the Optical character recognition (OCR) of the document. The second part extracts the mathematical expressions, and the third part converts the extracted mathematical expressions to MathML. The output from IntelliMath is the MathML which is fed to the NVDA screen reader that renders it to an audio output.

Figure 2 below shows the process diagram/ flow- chart of the design of IntelliMath. The input to the system is a pdf document which contains the mathematics content in the form of images. The user opens the pdf document with the help of a screen reader (NVDA). The screen reader segregates the non-mathematical (textual) and mathematical content. The non-mathematical part goes to the screen reader and the audio is produced in the usual way. The mathematical part goes to the IntelliMath plugin which converts the mathematics formulae/expressions into an audio in a three-stage process. The 3-stage process can be described as follows: (1) Extraction of Mathematical expressions, (2) Conversion of extracted expressions into MathML and (3) Conversion of MathML into an audio (Chauhan, 2019). This three-stage process is accomplished by the developed tool through this study – IntelliMath.

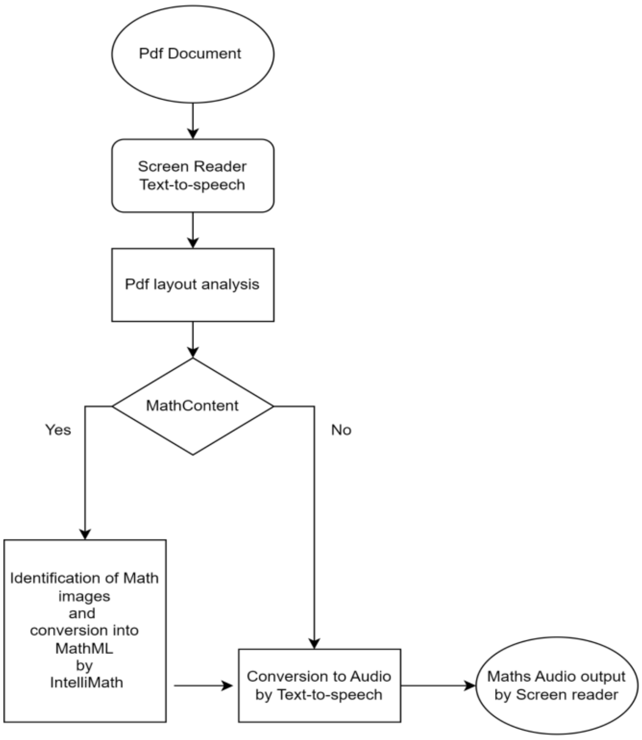

Figure 2: Process diagram/ flow-chart of the design of IntelliMath

Development

IntelliMath tool is developed as a plug-in to NVDA (NV Access, 2024) screen reader. NVDA is a free, open-source screen reader for windows. The non-profit NV access sets the roadmap and future of NVDA. IntelliMath was built by using two programming languages- Python3 and C#. The extensive library support and ease of use are the two reasons for choosing the two languages. The project has been tested on Windows 7 Home diction x64 and Windows 10 professional edition x64.

Methodology

To address all the three aims of the research, the research needed a blend of methodologies which covered the Quantitative and Qualitative aspects of the study. Cohen, Manion and Morrison (2011) stated that using a combination of research methodologies is a better approach rather than the slavish adherence to any one methodology. Through an extensive literature review of the existing research methodologies in education and the relativity of the current research inquiry, the researcher concluded adapting “Mixed method design”. The present study is built on elements of constructivism (Schwandt, 1994; Taylor, 1994; Von Glasersfeld,1987) and critical theory paradigms (Giroux, 1983). Mixed methods not only combine the quantitative and qualitative research methods but give a pragmatic perspective to a research problem (Sahin & Öztürk, 2019). The quantitative part of this research relates with the Experimental methodology (Cohen & Manion, 2011) as it collects the data in a controlled way with the same group of participants before and after the intervention of an independent variable which is the reader (human reader vs IntelliMath) and noting the change in the dependent variables such as the numerical scores in the Questionnaire. The qualitative part needed a methodology that covered the real-life scenarios of the participants' experience. A case study enables readers to understand ideas more clearly than simply by presenting them through principles or abstract theory by providing examples of real people in real situations (Cohen, Manion, 2011). It helps readers to understand how ideas and abstract principles can be put together (Yin, 2009). Case studies are recognised less as a methodology and more by reporting the real-life, complex, dynamic and unfolding interactions of events, human relationships and other factors in a unique instance (Hitchcock & Hughes, 1995).

Results

The results signify that the research objectives have been met and achieved in the way presumed by the researcher.

Data Collection

IntelliMath was tested with the students enrolled in the first or second year of tertiary education at three different Sri Lankan Universities. All the students had a prior knowledge of O-level mathematics. The data was collected from 25 students enrolled in 'The Employee Federation of Ceylon, Colombo-Sri Lanka' which provides ICT training to the people with vision impairments. The age range of the participants of the research was from 23 years to 30 years old. The manager of a specialised Training and disability resource centre helped the researcher to recruit participants on a voluntary basis.

Permission was obtained through Curtin University before data collection, this ensured that the study had support and met acceptable standards. A candidacy proposal was submitted, and an ethics form was reviewed, approved with the approval number (HRE2019-0464). Written permissions were obtained from the head of the Institution and students of The Employee Federation of Ceylon, Colombo-Sri Lanka before undertaking any tests. The researcher personally visited Colombo, Sri Lanka for the data collection. Participating students were inducted to use the developed automated tool- IntelliMath. A written statement of guarantee was provided for privacy and confidentiality to individuals from whom the data is collected. The data taken from the students was non-identifiable. There were no personal questions asked. The research was conducted very respectfully, and integrity was maintained throughout the research. The contribution and feedback provided by the participants was acknowledged in a way that retained confidentiality. The participants were given individual slots to test the tool. The quantitative data was collected in two phases. In the first phase the sample mathematical equations (calculus equations) were read/ described by a human reader/ reading assistant to the vision impaired student/participant and in the second round the same equations were described and presented by the automated tool- IntelliMath. In the second phase the data was collected using the Instruments for Quantitative and Qualitative data collection explained in the following section.

Instruments for data collection

Instrument for Quantitative data: A four-scale Experience Perception Survey named **Questionnaire-IntelliMath** was completed by all participating students. Scales of Ease, Motivation, Efficacy and Satisfaction measured the student's experience with the tool. Scale of Ease and satisfaction have been adopted from (Lund, 2001) and modified to fit this study as it shows a similar situation of software usability. Through the literature review no appropriate scale of efficacy of program and motivation was available, so a new scale was developed and validated in the study. The response was collected on a five-point Likert Scale ranging from strongly disagree to strongly agree ranging from 1 to 5. (Nemoto & Beglar, 2014). The Questionnaire designed for the study was based on the experiences of the participants after the usage of the accessible automated mathematics tool- IntelliMath. The questions were designed on the following attributes: user's ease of use, efficiency of program, motivation, and satisfaction. The study did not investigate the validation of the Questionnaire as it was designed for a small population (25 students); fell outside the scope of the study and wasn't feasible.

Instrument for Qualitative data: The Qualitative data was collected using the **Interview-IntelliMath** instrument. Once the quantitative data collection process was over then the researcher interviewed the same 25 participants in the same environment. There were four open-ended questions asked from each participant as per the instrument. The four questions asked were 'Was the automated tool easy to use?', 'How efficient was the tool in describing and helping in solving mathematics questions?', 'Are you motivated to study mathematics and other STEM courses after using the tool?', 'How satisfied are you after using this tool in terms of its efficiency and purpose of design?'. The participants responded to the questions and their responses were recorded by the researcher in terms of text and audio notes.

Research findings

The Quantitative data was then analysed by SPSS (Statistical package for social sciences) tool (IBM SPSS, 2024) which compared the differences using the effect size for scores of the students in two stages which could be attributed to concentration levels of the students while listening to a human and computer or the ability to understand the question delivered by a human and a computer. Single-item scores were used for the detailed analysis of an individual's response to each question in the test. The total score of an individual in each stage was calculated by adding all the single-item scores. The data is reported using scale means, and standard deviations, Differences based upon Gender and Age and by measuring the Correlations.

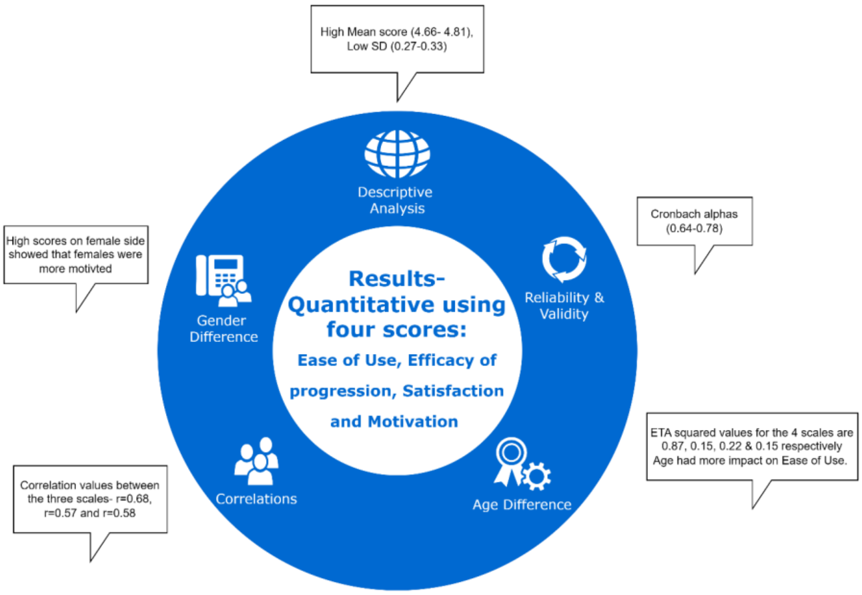

Figure 3: Key Quantitative findings

Figure 3 above shows the key findings for the Quantitative results in terms of Descriptive analysis, Reliability & Validity, Correlation, gender and age difference. The quantitative data analysis found relations between the feelings (ease of use, efficacy of program, satisfaction, and motivation), age and gender of the participants using IntelliMath tool for studying mathematics. The results in terms of high mean scores that ranged between 4.66 to 4.81 confirmed that the participants responses were more towards "strongly agreed". It signified that the participants felt that the tool was easy to use and efficient in its purpose and hence they were satisfied with its use and felt motivated to study mathematics and other STEM subjects. The low standard deviation which ranged between 0.27 and 0.33 also aids the results and signify that the data is clustered around the mean and not spread out. The Cronbach alphas obtained for the study ranged from 0.64 to 0.78 which signifies that the tool is reliable. The reliability score above 0.6 signifies the reliability of the scales of the questionnaire (Cronbach, 1951). The low reliability score for the scale of Ease of Use is attributed to the small sample size (25 participants). Reliability can also be seen when the measurement done repeatedly generates similar results (Williams, Wiggins, Vogt & Vogt, 2022). This research project (IntelliMath tool) upholds internal validity, external validity, and content validity. Internal validity was justifiable as the scores collected using the Questionnaire- IntelliMath were accurate because they were being taken in an examination environment and all the participants had common attributes. External validity is met as the results will be generalised in such a way which will be easily communicable to the outside world and the stakeholders working in the same direction (ScienceDirect, 2024; Reichardt, 2005). Correlation signifies the linear relationship between the two variables. The results indicate a non-significant positive relationship between Ease of Use and Efficacy of Progression, r = 0.68. In addition, there was also a non-significant positive relationship between the Ease of Use and Motivation, r = 0.57. Moreover, there is a positive non-significant relationship between Ease of Use and Satisfaction, r = 0.58. To sum up, the correlation results signify that as the ease-of-use increases, the level of efficacy of progression, motivation to study mathematics and satisfaction while using the IntelliMath tool increases. The results based on gender differences infer that the age has a small significance (~d=0.3) on the data collected. The female students were more satisfied in using tool and motivated towards learning mathematics as compared to the male students. The Age difference shows that the participants who are younger are more willing to learn and adapt to IntelliMath tool as compared to the elder ones. The biggest value of ETA squared (0.87) was seen for the ease-of-use category which concludes that the age had more significance on ease of use than all the other three categories. Overall, in terms of the quantitative analysis the testing has been successful, and the research aims have been addressed in an efficient way. The tool meets its purpose and can be easily used by the SVI in studying mathematics.

Qualitative data analysis was accomplished by the researcher by using the process of content analysis which included obtaining the descriptive information through categorisation and then formulating themes as per the responses provided by the participants. The categories emerged as the analysis of data was made through reading (Fraenkel & Wallen, 2003). Themes were identified for every question based upon the answers provided by the respondents. The researcher used a method which involved reading through the transcript, colour coding the text manually and then placing the text together as per the colour. It is suitable to use such method when the database of participants is small (25 participants), and the researcher does not feel like learning a new computer software program from scratch. The researcher used a method of coding the data by using Inductive codes where the codes are derived from the participants' views and responses. Open coding was used to create initial categories of information and Axial coding was used by selecting one open coding category as a core phenomenon and then relating other categories to it by grouping them (Strauss & Corbin, 1998; Glaser, 1992; Gallicano, 2013).Those codes were then abstracted into themes based upon the core ideas that were frequently talked about by the interviewees, salient, most evident and related to addressing the aim of the research question. Different colour codes were assigned to different themes and sub-themes by the researcher based upon the similarities and differences of the topics (Cohen and Manion, 2011).

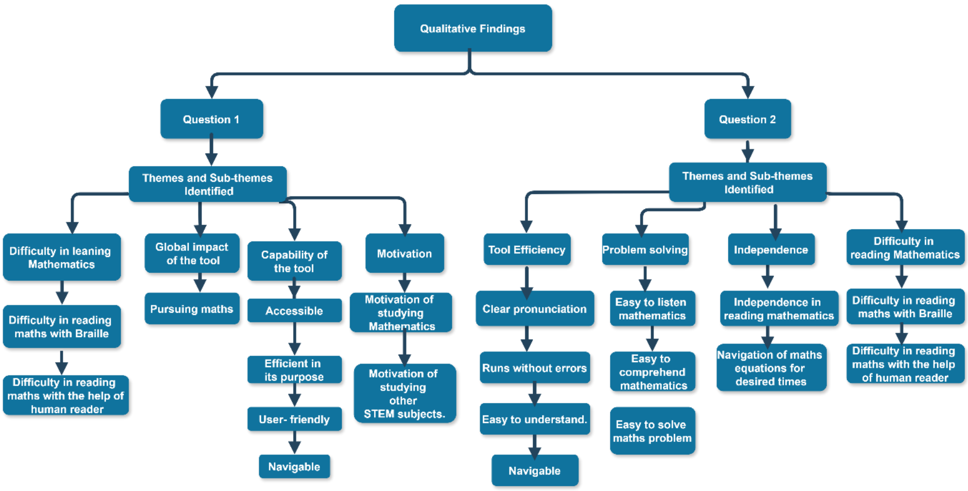

Figure 4: Key Qualitative findings

Figure 4 illustrates the key qualitative findings. The analysed data was validated with the process of peer review. A colleague working in the same field came out with similar themes which validated the process of coding and identification of themes and sub-themes. Furthermore, it was validated by the review of the supervisor who have good experience in this field of education. Through the qualitative data analysis achieved by coding and identification of themes it is concluded that there were different groups of students who identified common challenges in studying Maths and STEM related subjects and the benefits of using IntelliMath tool. It signifies that the students with vision impairments would like to use the IntelliMath tool in their daily life for the ease of reading scientific content, study Mathematics and STEM subjects.

Discussion and Conclusion

The data was collected and analysed in both quantitative and qualitative aspects which fulfilled the research objectives as it included the development of a tool fulfilling the gap identified and the feelings of the participants in using the same tool. The data indicated that the participants were highly satisfied in using the IntelliMath tool in terms of its usage, ease of access and efficiency. The participants were already familiar with the NVDA screen reader which made the use of IntelliMath easier by using the same/similar hot keys combination. They confirmed that IntelliMath meets its purpose by clearly outputting the equation and delivering the correct content intelligibly which was not the case with the human readers and Braille. The navigation feature of IntelliMath gave the flexibility of navigating within the expressions and sub-expressions. It brought an ease of going back to the expression again and again until it is fully read and understood by the user.

Furthermore, the participants of the study felt motivated to study mathematics as a subject which was a subject they are not likely to choose. Mathematics is generally not a preferred subject for the students with vision impairments as it is very difficult for them to comprehend because of its graphical, non-linear and non-accessible nature. The first step to understand any subject is to be able to read its contents. If SVI will read the contents of Mathematics clearly and correctly then they will be able to understand it. IntelliMath solves the first problem by reading the mathematics equations without any confusion and errors making it easy for the SVI to understand the subject in a right way. The tertiary level students suggested to introduce the tool at high-school level so that the SVI are motivated to study mathematics and other STEM subjects right from the beginning so that they do not hesitate to opt for science stream.

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