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Perspectives in Assistive Technology

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STEM Access for the Blind and Visually Impaired

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Overview

Science, Technology, Engineering and Mathematics have been a distant reality for the blind and visually challenged in the past. While the Nemeth Braille Code¹ has provided an opportunity for some blind students in North America to pursue Sciences, it has not yet permeated the rest of the world, resulting in very few blind students across the globe being able to study these subjects. In fact, the statistics from the National Science Foundation regarding participation of the blind in STEM courses in the United States are not very encouraging either. Thanks to the advent of assistive technology (screen readers, OCR software, Braille embossers etc), presenting scientific material in a wide array of accessible formats has now indeed become manageable. This research focuses on the accessibility of STEM content, and discusses the various options-both technological and non-technological-for managing Science. This also analyzes the current shortcomings, and proposes strategies to improve the current situation, both in developed as well as developing nations.

This research draws from the experiences of a large number of blind students from different countries, including the United States, the United Kingdom, India, among others. Further, views of various other stakeholders such as teachers of the visually impaired, parents, accessibility experts etc. have also been included.

The Problem

Students who are blind or visually impaired have traditionally been kept out of Science classes. This has been due to five major reasons.

1. Reading scientific content: There has been a dearth of adequate accessible STEM content in the past. Due to nonlinearity and technicalities involved in Science content, the OCR software used by the blind have not been able to recognize scientific documents accurately, resulting in a serious shortage of scientific textbooks, handouts and papers.
2. Writing scientific content: It is of paramount importance for the student to compose scientific documents for grading and for their own reference. This has been a great challenge in the past. Replete with technical notations and symbols, typing Science using standard word processing software (yielding the same output as that produced by a sighted person) has been a big problem.
3. Access to diagrams and graphs: With very few embossers and related products readily available (cost being a deterrent), blind students have not been able to analyze and work with diagrams and graphs which are central to a clear understanding of STEM as a discipline.
4. Building conceptual ability and performing scratch work²: Conceptual ability is the essence of a productive learning experience in the STEM. However, unfortunately, there has

¹ The Nemeth Braille Code for Mathematics is a Braille code for encoding mathematical and scientific notation linearly using standard six-dot Braille cells for tactile reading by the blind. (http://en.wikipedia.org/wiki/Nemeth_Braille)

² Scratch work refers to the intermediate steps while performing a computation

been a severe scarcity of resources providing for a solid conceptual understanding of the STEM for the blind. In addition, there has been no comprehensive and affordable tool that could enable a blind person to carry out all the scratch work/computations independently to the same extent as a sighted.

5. Active participation in Science laboratories: In the past, blind and visually impaired students have generally been passive in their participation in Science labs, if they choose to participate at all. In other words, they are devoid the opportunity of taking readings, analyzing observations, reaching conclusions, documenting observations etc. Instead, they merely understand the theoretical rationale behind the experiment. This robs them of the joy of experimentation and hands-on learning-something every Science student cherishes.

Available options

Several solutions are now available enhancing STEM accessibility. These software have been divided into categories depending upon their intended purpose.

An introduction to MathML and LaTeX

Before discussing specific software, it is crucial to understand LaTeX and MathML. These are two mainstream software that help compose and edit technical documents.

LaTeX is a widely used typesetting language used for composing Mathematics and documents containing other technical content. The language has a predefined syntax for generating various notations and symbols that constitute an expression. Each statement begins with a \backslash , and Mathematical notations are enclosed within braces. Most of the mnemonics used to denote mathematical notations are trivial, and can be easily mastered in a short span of time. Nevertheless, it sometimes becomes difficult to code using the language, especially when working with large documents.

MathML is a format for presenting Mathematics and is an extension of XML. the format is being widely used by academic community and by the DAISY Consortium³, besides people with technical expertise. MathML documents, when viewed on the web, in conjunction with suitable add-ins, can considerably enhance the accessibility of Mathematical and Scientific documents.

Reading STEM content

While Nemeth Braille is the most popular method for reading math and Science in North America, it is less common in other parts of the world (especially the developing

³ The DAISY Consortium is a global consortium of organizations committed to a common vision, i.e. creating the best way and most accessible way to read and publish. (http://daisy.org/about_us)

world). Statistics from the DAISY Forum of India reveal that there are less than five blind schools in India that impart training in Nemeth Braille. Furthermore, Braille embossers tend to be rather expensive for several emerging economies.

Fortunately, several other technological solutions now exist that can aid the blind students to actively participate and comprehend material in the STEM.

Math Player and Math DAISY

Developed by Design Science, Inc., MathPlayer is a plug-in which when used with IE9, renders MathML documents converted into webpages accessible. The plug-in takes up a standard Mathematical document, and replaces a non-linear expression with its corresponding accessible linear representation. For instance, a fraction with a numerator and denominator is converted from its standard non-linear form, to a linear form, with the word `over` separating the numerator and the denominator. To avoid any ambiguity, it makes use of parentheses, brackets and braces to demarcate different components in an expression. Further, several software allow the conversion of various Mathematical formats into MathML webpage, thereby making a vast range of STEM content accessible. for instance, LaTeX documents can be converted into MathML using tex4ht, Chatty Infty and Scientific Notebook.

While Math Player has indeed enhanced accessibility of math content, the introduction of a `time lag model` can further improve the software. By `time lag`, it is implied that there is a pause to denote different operators in an equation (rather than specifically announcing "open parenthesis" and "closed parenthesis" each time). This will help better retain and understand a long equation.

As yet another software from Design Science, MathDaisy™ enables teachers and others to save documents in the DAISY Digital Talking Book format⁴. Students can use MathPlayer™-enabled DAISY player software to read classroom materials in the manner that suits their abilities and preferences best. MathDaisy works with Microsoft Word, Microsoft's Save As DAISY add-in, and MathType. As one might guess from its name, Save As DAISY adds a "Save As DAISY" menu item to Word's File menu. This command saves the document as a DAISY Digital Talking Book ready to be used in an eBook reader. MathDaisy enhances the Word-to-DAISY conversion process, converting the equations in the document to MathML as required by the DAISY format.

Math Player and `Save as DAISY` add-in are freely available on the web. Office 2010 also includes a `save as DAISY` option. Further, these software support a wide range of Mathematics, well beyond university Mathematics. These software, however, are restricted to

⁴ The DAISY format is one of the most popular formats for digital accessible textbooks among the print impaired community.

accessible conversion of text, and do not help analyze diagrams. Plane geometry, therefore, remains a concern.

MathJax

Design with a view to improve the portability of Math content, MathJax is an open source JavaScript display engine for Mathematics. The primary objective of the software is to display Mathematics content suitably irrespective of the web browser or device used. Besides its primary objective, the software also facilitates several other important operations such as copying and pasting Mathematics, simple integration and provides a rich API.

For Mathematics content to be rendered accessible, MathJax must necessarily be used with MathPlayer add-in from Design Science. When used with MathPlayer, good results are obtained. Since MathJax can convert TeX to MathML, the combination of MathJax and MathPlayer can make many more web pages, blogs, and wikis accessible. Therefore, using MathJax increases the amount of Mathematical content that can be accessed by individuals with print disabilities.

Infty Reader

The InftyReader OCR application is an optical character recognition software that effectively recognizes technical content containing Mathematics and Science. It recognizes scientific documents scanned from paper and can also effectively recognise documents in PDF format. Furthermore, it recognizes complicated math expressions, tables, graphs and other technical notations and converts them to accessible formats. The software can be used by people with print disabilities in combination with the ChattyInfty accessible scientific editor application. ChattyInfty provides speech access for reading and writing math and editing the output of InftyReader. Sighted people can use InftyReader with the free Infty Editor to edit InftyReader output and produce accessible scientific content.

InftyReader and ChattyInfty are made by the Infty Project and are sold through Science Accessibility Net. A trial version of the software can be downloaded from Science Accessibility Net located on the web at <http://www.sciaccess.net/en/>. The full version of the software needs to be purchased through Science Accessibility Net.

Here are a few salient features of the software:

- It uses the "ExpressReaderPro", OCR engine from Toshiba Corporation and the "WinReader" OCR application from MediaDrive Corporation simultaneously to recognize characters in regular text. The latest version of the software when purchased also has an add-in that can work in conjunction with ABBYY Fine Reader⁵.
- It uses an OCR engine developed by Infty to recognize math and scientific formulas.
- It can recognize tables containing math expressions.
- It can convert black and white scanned documents and PDF files.
- It recognizes individual pages in a PDF file.
- The output generated after processing can be in one of several available formats including IML, LaTeX, Hr-TeX, XHTML+MathML and even Microsoft Word 2007 (XML).

However, it is to be noted that great care must be adopted while scanning the document. Several instructions (regarding paper placement, DPI level, colour and so on) need to be religiously followed to ensure optimum results. Further, the software documentation available online recommends scanning the document as a TIFF or GIF, and then converting it to the accessible versions later. The results obtained, however, after following this route are unsatisfactory. Instead, it is recommended that the document be scanned as a PDF (using Fine Reader), and then exported to MathML.

Manipulation of screen reader dictionary files

Certain changes can be made to the dictionary files to have the screen readers pronounce certain symbols the way the user would want them pronounced. The following is an outline of the process using JAWS for Windows, the most popular screen reader.

1. Insert the symbol which is not being read out by JAWS.
2. Press INS+F2.
3. Press D and reach `dictionary manager`. Hit the enter/return key.
4. Press CTRL+shift+D.
5. Tab to the `add` button, and press enter.
6. Tab to the field `actual word`. The original symbol will pop up.
7. Tab to the `replacement word`. Spell out the symbol name.
8. Tab to okay button and press enter. Close the dictionary manager and choose `yes` when prompted for saving changes.

⁵ ABBYY Fine Reader is the most popular OCR software used for scanning and converting standard (non-scientific content) into accessible formats

Shortcomings

Despite several developments in trying to enhance access to Math and Science content, there continues to be significant challenges in truly enabling a blind student to take advantage of the STEM resources on an equal basis. This is primarily due to two problems:

- a. Despite the availability of several products and techniques, there is very little knowledge about these tools and strategies, even within the disability sector.
- b. Several tools are pretty costly (being especially true for students in developing countries). Yet other tools cause ambiguities when interpreting the results. For instance, the OCR tools do not provide 100% accuracy. Similarly, when complex equations are read with math Player, there tends to be a lot of confusion in analyzing the equation.

Proposal

Lack of awareness is perhaps the biggest challenge plaguing the disability community in general. This is especially pertinent in this context. Training needs to be organized for teachers in schools for the blind to sensitize and educate them about these software. Hands-on workshops need to be organized for students, not only helping them to access STEM documents, but also to gain feedback and suggestions for developers. Repositories need to be established allowing ready access to textbooks. Mainstream tech giants such as Microsoft and Google need to be encouraged to integrate these features into their software in keeping with the idea of Universal Design.

On a technical note, models like the `time lag` model discussed above should be considered. Further, there should be greater technical collaboration between various institutions working for enhancing accessibility across the globe.

Writing STEM content

The ability to effectively convey observations and conclusions is crucial. Writing helps us achieve this. Unfortunately, writing does not come without its own share of complications for blind students. The non-linearity in written Mathematics, coupled with technical notations in the Sciences, often prove to be problematic for students with print disabilities. Nemeth Braille has been, and continues to be, the most popular method of writing Math and Science documents in North America. There are several other tools available though that can help students preferring auditory over tactual instruction.

MathType

Developed by Design Science, Inc., MathType is a WYSIWYG editor⁶ that has gained widespread momentum to write Mathematics among the sighted. This is primarily due to the flexibility of not mastering the syntax associated with scripting languages such as LaTeX. Unfortunately, the blind community has not benefited from the WYSIWYG feature of the software as the WYSIWYG editing interface is mostly inaccessible. However, the software provides the option of writing the Mathematical content in a scripting language, and the rest of the document using standard word processing features. This feature can ease writing Mathematics substantially. Rather than learning all the keywords associated with composing and formatting a document, one can easily master LaTeX Mathematical syntax (to write Mathematical equations), and then use a simple keystroke to convert all LaTeX equations into MathType equations. The document can then be formatted using standard formatting commands. Conversely, if MathType is used for creating textbooks and the electronic copy is provided to a blind user, a simple keystroke (ALT+backslash) can convert all the MathType equations into their corresponding LaTeX representation, thereby enhancing accessibility.

The software is a shareware. A 30-day trial version of the software can be downloaded from Design Science's website.

Chatty Infty

Developed as a part of the Infty Project, Chatty Infty allows entering Mathematical expression in one of three ways:

1. LaTeX mode: the user can enter Mathematical expressions/equations in LaTeX, and the program automatically converts them to standard readable Mathematics once the user hits the enter/return key.
2. Instead of learning LaTeX Mathematical syntax, the user can make use of Chatty Infty-specific Mathematical syntax, which has keywords quite similar to the English words for various symbols in Mathematics.
3. The drop-down menu option: The user can select symbols from the drop-down menu. Once a particular symbol is selected, an interface conducive for writing expressions involving that symbol pops up. As an example, if the user selects `\frac`, a window pops up with two text boxes allowing the user to specify the numerator and denominator. An enter key prints the expression in standard readable mathematics.

Lean Math

⁶ What you see is what you get (WYSIWYG) editor relies on menu options for creation of documents, rather than conforming to a syntactical language

Lean Math is a new and powerful way of writing mathematics. It adopts a similar functionality as Chatty Infty in that simple keywords are used to represent the various notations and constructs used in Mathematics and Science. One can toggle between the general and the Lean Math modes. The general mode is used for entering Mathematics, while the Lean Math mode is primarily used for reading and editing entered expressions/equations. The software is still being further improved. As it stands today, navigation in the Lean Math mode is slightly problematic. The software supports a vast range of Mathematical topics- fractions, superscripts, subscripts, matrices, determinants, trigonometric functions etc.

Writing Math and Science using a standard word processor

While several specialized packages are available to compose technical documents containing Mathematics and Science, it is not always very convenient to master the syntax associated with these scripting languages. Often, a better approach is to use a standard word processor, taking advantage of the symbols commonly available. This, however, has its own share of limitations.

- A. Many of the symbols commonly used in Math and Science are not read out by JAWS screen reader once inserted. This renders insertion almost useless as the blind user cannot possibly review or edit his work.
- B. NVDA⁷ is slightly better than JAWS in terms of reading technical content, but cannot be used to read symbols used in Calculus.
- C. If an alternate, more accessible approach is utilized by the user (by spelling out the symbol), it compromises on the presentation.

Manipulation of the screen reader dictionary files (discussed above) can help. One might also take advantage of features like auto text commonly available in word processors.

Shortcomings

It is evident that there is no one ideal tool that facilitates writing Mathematics and Science. Each software has its own pros and cons. For instance, math Type requires the user to know LaTeX. Lean Math is still under development phase, and as of now, suffers from issues like lack of easy navigation etc. Coupled with these challenges is the cost, which makes it difficult for students in developing countries. Yet another problem is that all of these software are developed by specialised assistive technology companies. This implies that the user cannot make use of these features when using a standard universal software.

⁷ Non-Visual Desktop Access (NVDA) is an open-source screen reader that is gaining widespread momentum, especially in developing countries.

Proposal

The best solution is to incorporate these accessibility features in standard packages. Moreover, there needs to be greater collaboration between assistive technology companies to share software features with a view to developing an ideal software bundled with the salient features of all the software available today. Students need to be encouraged to write Math and Science independently.

Access to diagrams and graphs

Getting an intuition of diagrams and graphs has always remained a big challenge for the visually challenged. While tactile graphs and diagrams present one solution (and, in several cases, the best solution), it is not always very convenient and easy to produce tactile diagrams instantaneously or even in the long run (especially in the developing world). Moreover, some students may prefer verbal descriptions of graphs and auditory representations (tonal representation) of graph over tactile representation. This section discusses about two such software-Audio Graphing Calculator from ViewPlus Technologies and MathTrax from NASA.

Both these software employ sonography (representing the nature of the curve using different frequencies). In fact, MathTrax not only produces a tonal variation, but also returns the verbal description of the graph. While the tonal representation does not provide a complete picture, it provides a basic idea of the monotonicity⁸ of the curve. This information can help the students get a basic layout of the graph.

Audio Graphing Calculator is a shareware, i.e. is available for free download on a limited basis. A 30-day trial version is available for free download at <http://www.viewplus.com>. MathTrax is a freeware, i.e. can be freely downloaded from NASA's website located at <http://prime.jsc.nasa.gov/MathTrax/>. In fact, NASA welcomes feedback from end users, and is also willing to share the source code for further development and improvements.

The interface employed by AGC is slightly complex and complicated for a first-time user. While the `readme file` describes the options clearly, navigation can prove to be a slight concern for a person having very little familiarity with Computer. Once the menu options are understood clearly, accessibility is not a concern. MathTrax, on the other hand, is easy to use, and does not have any interface challenges as such.

⁸ Monotonicity refers to the basic characteristics of a curve (increasing/decreasing, information about gradients etc.)

As of now, both the software support standard curves. While AGC allows importing curves too, the representation is not that accurate when compared to the standard curves.

Personal observations from user testing

The following are my personal observations from the user testing of these two software.

- a. The verbal descriptions of the curve provided by MathTrax are more helpful than that provided by AGC.
- b. The tonal representation is more clear and informative in case of AGC. The software also provides several options to customize the tonal representation, using such options as time, range of frequencies, and other special sounds to denote origin etc.

Shortcomings

The cost of the Audio Graphing Calculator may prove to be an impediment, especially for students from developing countries. Moreover, representation of curves in Economics and statistics (such as the bell-shaped curve used in mean and standard deviations and related topics) and their relevant descriptions has not been addressed. Further, although the verbal description provided by MathTrax is of immense help, it may sometimes not provide the particular information that the user requires.

Proposal

An option or add-in built into a mainstream application capable of sonography and providing verbal description is the ideal way to go forward. Furthermore, rather than a static description popping up, the interface should be dynamic in that the software should be able to return the specific information requested by the user. This will help eliminate the possibility of missing out on any particular characteristic sought. A 3D representation such as that provided by Seeing With Sound⁹ might also be an innovative project to work on.

Building conceptual ability and managing scratch work

⁹ Seeing Without Sound is an innovative project that makes use of stereophonic sound to convey 3D images.

Math and Science are all about concepts and computations. Unfortunately, very few resources exist that provide blind students an opportunity to hone their conceptual ability and computations. While Taylor Frame¹⁰ is one tool that has been used by the blind in the past, it sometimes becomes very tedious for some students to work out lengthy computations, keeping track of the intermediate steps (not to say it cannot be done; several students prefer using a Taylor Frame with a Perkin's Braille to keep track of the intermediate steps). This section will discuss other tools available today that can help students solidify their concepts and ease calculations.

Cuberythm

The Cuberythm is pretty much like the Taylor Frame, except that it does not use type in different orientations to denote different numbers. Instead, it has numbers embossed in Braille. This helps Braille-literate users to work out computations without memorizing different orientations of type for working out arithmetic and algebraic computations.

Cranmer abacus

Abacus is one of the oldest tools used for computations. While it is no longer used in most parts of the world (except People's Republic of China and a few other countries), it has been particularly popular with the blind community. The Cranmer abacus has been particularly developed for the blind, and is known to speed up calculations substantially. The American Foundation for the Blind publishes online manuals to instruct blind users on the use of this device. Hadley School for the Blind based in Illinois also offers distance learning courses in the use of abacus.

VP Arithmetic and VP Algebra

Developed by Henter Math, LLC., Virtual Pencil Arithmetic and Virtual Pencil Algebra are two software that are aimed at providing the same opportunity to a blind student as a sighted student—that of using a pencil to work out Mathematical problems. The only difference is that these software use a virtual pencil rather than a traditional pencil. These software utilize a virtual interface that allows a blind student to navigate and edit values and write intermediate steps, thereby understanding concepts better.

The software moves to the right spot on the “paper”, guided by the user, and inputs the answers that the user selects. It can edit numbers and variables, insert fractions or square roots

¹⁰ The Taylor Frame consists of an aluminium frame and a set of metal pegs or type. Different orientations of these type represent various digits and signs in Mathematics.

or other structures, and copy whole equations or expressions. When used with a screen reader the numbers and actions are read out loud. The user must navigate the screen and provide the input.

VP Arithmetic handles addition, subtraction, multiplication, and division, with fractions and decimals. On the other hand, VP Algebra handles radicals, exponents, subscripts, Greek letters, absolute values, matrices, fractions, and many editing features.

The two software are shareware, i.e. they are available on a limited basis free of cost. For unlimited access, payment is required (price of VP Arithmetic is US\$199, while that of VP Algebra is US\$399).

Some accessible calculators

Often, calculators are permitted on tests and exams. In fact, calculators are almost always used in a professional setting. This section will discuss about some accessible calculators.

IPad App talking scientific calculator

The IPad app Talking Scientific Calculator provides for an accessible scientific calculator. The calculator has all the functions which are generally available in a scientific calculator including the trigonometric, logarithmic, arithmetic, exponential, hexadecimal and random functions. In other words, the calculator is pretty much the same as a standard scientific calculator with accessibility features built-in.

The software employs the double tap model of the touch-screen phones¹¹. However, as a lot of functions and operators are available, navigation becomes slightly difficult (as it becomes challenging to keep track of the exact position of a particular operator on the screen).

Microsoft's standard calculator

¹¹ The double tap model is a model that facilitates blind users to use touch screen devices effectively. When a device is tapped once, the screen reading utility on the phone reads out the menu option. To select the option, the user must tap it twice.

The standard calculator that comes as a part of Windows OS is very accessible with screen readers. Capable of performing all standard operations alongwith scientific operations such as logarithmic, trigonometric, exponential and other such functions, it uses a very simple and accessible interface.

Calculations using a spreadsheet

Microsoft Excel or a similar spreadsheet application can also be used to work out Mathematical computations. Detailed steps can be found in `Annexure A`.

Shortcomings

While the iPad Talking Calculator app supports a large number of operations, it can often be difficult to find the precise operator on the screen. This becomes a serious problem due to the large number of operators and functions used in Mathematics. Moreover, the VP Arithmetic and Algebra packages support a limited number of operations and functions, and hence can be used only upto middle school level.

Proposal

Microsoft should consider incorporating some of the features of Virtual Pencil Arithmetic and Algebra in Microsoft Excel. Further, a model needs to be introduced that can help in decreasing the clutter on the screen in case of smart phone calculator apps.

Managing laboratory work

The first reason that most cite for the blind and visually impaired not being able to pursue Sciences is the inability to manage laboratory work. Thanks to advent of assistive technology and other innovative strategies, the blind can indeed participate actively in Science labs.

Non-technological solutions

The non-technological solutions for managing Science labs have been included as `Annexure B`.

Technological solutions

Talking LabQuest

The Vernier Original LabQuest has been adapted by Independence Science with Sci-Voice Access Software to improve access to science experiments for students who are visually impaired. This mainstream device is consistently used by sighted peers and is a one-of-a-kind tool for collecting/analyzing scientific data. Text-to-speech has been added for accessible data collection, navigation through the menu, data table, periodic table and statistical analysis features. This device is recommended for use in high school or college curriculum for studying chemistry, biology, physics, earth science and any other lab course. For data collection, it is imperative to use sensors in conjunction with this device.

Here are a few salient features of the Sci-Voice Software:

- Speaks and records data measurements in real time.
- Periodic table with 20 spoken attributes for each element.
- On board statistical analysis of data sets.
- Export to Logger Pro with Sci-Voice app for further analysis and tactile printing.

This device can undoubtedly be used effectively by blind students for hands-on Science learning. The only impediment, though, is the cost. As of March 2014, the talking LabQuest costs US\$1495.

Shortcomings

The technological solutions available in the market for making Science learning accessible, unfortunately, are rather expensive for students in developing, and in fact, even developed countries.

Proposal

The technological solutions for making Science labs accessible have been introduced very recently, and the cost at present is therefore justified. However, non-availability of these expensive products does not mean that blind students cannot participate in the labs. As discussed in Annexure B, there are several non-technological solutions that can be used. Furthermore, the student should be encouraged to use other senses, especially in experiments that are not solely dependent on visual cues. The Governments should also consider not only bringing these products to their students, but also investing in research for other such similar products.

Some other handy non-technological aids

There are a few other non-technological devices and methods that are being widely used to help blind students get a good understanding of diagrams. These have been discussed in Annexure C.

Conclusion

As is evident, several software and products are now available that can enable a blind student to actively participate and excel in STEM classes. The need of the hour is to further improve these software, while also encouraging young blind students to use them. The idea of Universal Design also needs to be emphasised, which can ultimately bring down the cost substantially, thereby enhancing access to these products. It is also important to involve stakeholders in the testing and development phase to get a better perspective from the broader community. Finally, needless to say, bringing about awareness in the general public is the key to empowering the blind and helping them pursue STEM fields, which was hitherto considered impossible.

Annexure A

Writing equations

This is a manual for helping students with visual impairment understand the process to write their documents using a standard word processor without any specialised software.

Symbols are the building blocks of an equation. However, a symbol has practically little, or in fact no significance unless it is put to use in writing equations or in computations. This section seeks to examine how equations can be easily and unambiguously written on a word processor.

(Note: For purposes of this discussion, parentheses refer to (.....), while left and right brackets refer to [.....].)

- a. Place your cursor at the beginning of the line.
 - b. If the equation or the expression begins with an alphabet, simply type it out just as you would have normally typed it in a plain text document. Similarly, if the first element in the expression/equation happens to be a symbol, simply insert that symbol (using the symbol's dialog box).
 - c. Now, repeat step (b) for all of the elements in the equation until you encounter an over (upon) sign, i.e. you encounter a denominator.
 - d. To make sure that the entire forthcoming text is construed as denominator, enclose it in parentheses (.....).
 - e. If half of the text is denominator, and the text following it is the numerator of the next fraction, enclose the text of the first fraction in left and right brackets ([.....]), separating the two by enclosing each in separate parentheses. Subsequently, separate the denominator and the text of the numerator following it by enclosing the text of the following numerator in yet another left and right brackets.
- e.g.

Consider an expression

Numerator A+B with denominator C+D, followed by numerator E+F

Same as:

Numerator A+B with denominator C+D, times, numerator E+F

This will be typed out as:

$[(A+B)/(C+D)][E+F]$

- f. If the denominator contains two or more separate terms, enclose all of those terms within left and right brackets ([...]), and then enclose each separate term in parentheses.

The following examples illustrate ALL THE METHODS DESCRIBED ABOVE.

Illustration1

To type Einstein's mass-energy equivalence $e=mc^2$

- a. Type the first element e.
- b. Type the second element = (available on a standard qwerty keyboard).
- c. Type the third element m.
- d. Type the fourth element c.
- e. Type the fifth element ² (by inserting ² using the symbol's dialog box).

Illustration 2

To type $I = \frac{eE}{m\tau}$ with eE, denominator with m, followed by numerator tau (denoting time constant)

- a. Type the first element I.
- b. Type the second element =
- c. Now, enclose the first fraction within left and right brackets ([.....]).
- d. Enclose the numerator in brackets. So, type (Ee).
- e. Separate the numerator and denominator by a /.
- f. Since the denominator is a single element, you may or may not enclose it within parentheses. For simplicity, let us enclose it in parentheses.
- g. Now that one of the fractions has ended, close the first fraction with a right bracket or].
- h. Enclose the second fraction (consisting of just the numerator, implying unity in the denominator) in a second left and right brackets.

Turning in homework/assignments for grading

Homework and assignments can be written on a word processor by adopting the following process.

- a. Using the methods described above (both insertion of symbols and writing equations), write your text document containing Math and science just as any other text document.

- b. Only use line feeds (press the enter/return key) when you want to go to the next line. Do not use it, for instance, to denote denominators/subscripts etc.
- c. For symbols not readily available to you (due to inaccessibility of the screen reader being used), you can substitute those symbols with complete words representing those symbols.
- d. If you have sighted assistance later on, you may replace particular words you used in lieu of the symbols with the corresponding symbols using the `replace all` feature available in notepad/MS Word.
- e. If you do not have sighted assistance, you may want to consult your teachers for permission to use complete words denoting the symbol in lieu of the symbol.

Managing scratch/rough work/calculations using a spreadsheet

Spreadsheets can be used for facilitating calculations in the following two ways:

- a. Use the auto-calculate feature: Where calculators are permitted, you can use the auto-calculate feature of MS Excel to perform calculations. This employs Excel formulae to perform calculations. For a more rigorous treatment of this topic, consult an Excel tutorial widely available online.
- b. You may perform calculations on a spreadsheet without using the auto-calculate feature. Adopt the following course of action:
 1. Position your cursor on cell B2 (this will change for the nature of computations, and the user must make an intelligent choice). The cursor has been positioned in cell B2 to facilitate carries/borrows (used in addition and subtraction) and computation of products involving more than one digit.
 2. Type a single digit in each of the cells.
 3. Here after, perform addition and subtraction just as you did on Taylor Frame. There is no need to write the operator, however, and it is advised to keep track of it mentally as you progress.

Illustration

The spreadsheet below shows the sum of 256 and 529.

	1		
2	5	6	
5	2	9	
7	8	5	

Annexure B

Adaptations for accessible Science labs

(Note: Some content in this section has been adapted from a similar study conducted by University of Delhi in India)

Some suggested modifications in setups:

1. Electrical Components- resistors, capacitors, transistors, integrated circuits, batteries, wires, clips, wire coils: Electrical components do not need to be modified for use by the student. However, many components are color coded, such as resistors, and would require sighted assistance to convey this information to the blind student.
2. Funnels: Funnels can be used to create a greater accuracy when transferring a liquid or solid from one container to another.
3. LEGOs and modeling kits: Both LEGOs and modeling kits require no modification because their components are brightly colored and entirely identifiable tactually.
4. Microphones: Microphones are audible input devices and can be used easily by students with any level of visual impairment.
5. Pulleys: Pulleys are often used in a series. Because there are many connections, the student will need to be given enough time to understand how they are all connected. Remember that creating a whole picture from tactually gathered information takes longer.
6. Springs: Springs are often used in studies of mechanics. The student can obtain a strong understanding of the properties of springs by experimenting with them.
7. Tuning forks: Tuning forks are audible and tactual devices that give no visual output. The one consideration is their placement in experiments in relation to other objects.

Labelling:

1. Beakers, Flasks, Test Tubes, and Graduated Cylinders: To make these glass objects more accessible to those with low vision they can be marked. The markings can be made with either colored paint or colored tape. To further emphasize the container, placing a black piece of paper behind it can increase the contrast. Tactual marking can also be added to the container. These can be raised lines at intervals or Braille numbers indicating the level. Since all of the objects are glass, they pose the risk of being dropped or inadvertently knocked over. This risk exists for all students and can be helped by careful placement of containers away from the edges of counters, placement in sturdy stands, and an uncluttered workspace.
2. Bottles (liquids): Whenever possible, plastic bottles with nozzles should be used. Otherwise, bottles containing liquids should be of a type that does not leak when being poured. Having a lip on the mouth of the bottle usually helps in orienting the bottle to another container for pouring, although some lips cause the bottle to drip.

3. Distance measures: General distance measures, such as rulers, meter sticks, or tape measures, can be easily adapted. They can have tactual markings made by placing various sizes of pins, etchings, or bumps to demarcate the fundamental units on the scale. For long distances meter wheels are useful because they click audibly with every revolution. Strings with regularly spaced knots can also be used to measure distances. Protractors only need tactual markings. Compasses can be used in conjunction with adapted rulers to produce the desired radii. Highly contrasting lines or enlarged number markings can aid low vision students.
4. Gas sources: In most labs the gas source is located at each lab station. Since there are many configurations of the sources, you will need to make modifications that suit the lab you work in. If there are other nozzles or handles nearby, they should be identified tactually and associated with their particular nozzles by tactually identifying the nozzles as well. When connecting hoses the student should have a tactual measure of the amount that the hose needs to be pushed on.
5. Labeling containers: Plastic labeling tape printed with Braille and/or tactual markers can be used to label containers. Tactual markers can be used either to label a particular substance or to indicate the type of material or associated safety risk (acid, base, flammable, poison, etc.). Large, distinctly colored warning labels can be used with partially sighted students. Containers should be organized and students should be taught to return them to a specific location, but this does not replace labeling the container itself. If possible, the shape of a particular container should be some indication of the substance inside (screw lid = solid, glass stopper = acid, plastic stopper = non-caustic liquid, etc.)

Analog dials and labelling

1. Air pumps: Air pumps are used when filling balloons or rockets for force experiments. The students with visual impairment need no modification for the use of this device. Some air pumps have analog air pressure meters that can be seen with magnification or read by the lab partner.
2. Devices With Digital Readouts: At present the following devices have a digital readout that is inaccessible to students with severe visual impairment.
 - Stopwatches
 - Voltmeter
 - Ammeter

Some companies currently make synthetic speech components, and it is possible that they will be included in other devices in the near future. As with other products, all dials and connections should be labelled in a way accessible to the students in the class. Although the devices' outputs are inaccessible, the student will be able to use them in a laboratory provided that their partner will read the digital readout.

3. Geiger counters and radioactive sources: The Geiger counter has an audible output. The blind or visually impaired student should be able to independently complete experiments using this apparatus with the exception of reading the numerical output, provided that the dials on the Geiger counter and the radioactive material are labeled.

Tactile or Audible Modifications

1. Balances: Manual single or double pan balances with pointers that can be touched (i.e. are not inside a casing) should be used. The pointer should be close enough to the scale to be able to touch both with one finger. Use narrow tactual markings to denote the various angles on the scale, and make sure that the height of the marking makes it either flush with or higher than the pointer. This will help the student to use the least amount of pressure to feel the pointer, reducing the problem of accidentally moving it from rest or preventing it from coming to rest accurately.
2. Light sources such as flashlights, bulbs, and LEDs: Bulbs and LEDs are most commonly used in electricity experiments to identify when there is current following through a circuit. This can easily be adapted by adding a sound source. A small speaker, piezo buzzer, or motor will emit a sound when a current is run through them, and like a light, the sound will get stronger with a stronger current. Flashlights that produce a greater amount of light should be used by students with low vision.

Special Equipment

1. Circuit diagrams: Circuit diagrams can be represented as raised line diagrams. Difficult circuits can be very confusing as raised line diagrams. Also, the elements of the circuit will need to have distinct tactual differences in shape to be distinguished.
2. Matches, splints, and tapers: Always get long handled matches, splints and tapers. This way the student's hands are away from the flame. Butane gun lighters are another alternative to matches, which keep the flame far from the student's hands and extinguish automatically.
3. Periodic table: The periodic table is used frequently in all chemistry classes. It is available as a Braille version and is also available as accessible electronic text.
4. Prisms, mirrors, and lenses: These objects are for the manipulation of light and its qualities. The objects themselves have no modifications, but their effects can be measured with a light probe. The light probe will beep when it is directed at light. Thus the student can identify where the light beam is before the prism or mirror and after. Another way to make these more accessible is to produce raised line drawings of phenomena.
5. Syringe: A syringe that is made for measuring chemicals can be of great use. For a visually impaired student to use such a device it is helpful to put tactual markings on the plunger indicating how much liquid is contained in the device. Tactual markings can be notches with Braille numbers as labels. Once a student learns to use this, it is a safe way to measure and transfer liquids of all kinds.

Advanced Tool Modification

In some cases, more advanced devices and more complicated adaptations can be useful in particular types of experiments. These require more time and/or more funds than simple adaptations. Most of them do not exclude use by sighted students, and in fact sighted students may enjoy using them.

1. **Air Tracks:** Air tracks can be very easily adapted for use by students with some residual vision, by using brightly colored sliders and/or sliders with light bulbs attached. Sliders with light bulbs are very common because they are very useful for experiments demonstrating constant and changing velocity and acceleration. It is much more difficult for severely visually impaired and blind students to fully utilize an air track, but they can explore it through touch and gain an understanding of the nearly frictionless surface.
2. **Bunsen burners:** Bunsen burners are one of the highest safety risks in a chemical laboratory. Therefore, extra precautions should be taken to prevent accidents. It is always a good idea to place a tripod around the burner to prevent hands from getting too close. The ring of the tripod also helps the student to locate the flame when heating test tubes or placing other small objects in the flame. If the student has residual sight, a piece of plain wire gauze placed on the tripod will glow bright orange in the flame. The student may need assistance from a sighted person to adjust the flame properly. If the burner has a valve at the bottom for adjusting airflow, the handle should be painted a bright color to make it easy to locate, but even students with residual sight may not be able to see the flame adequately to adjust it themselves. Self-igniting burners are also available. These are triggered by various stimuli including the flow of gas, activation of a motion sensor, or depression of a foot pedal. These can be expensive but they are the safest type of burner, especially because some models turn off automatically after the stimulus stops.
3. **Light Sensors:** Any sort of light sensor that is connected to a sound source is useful for severely visually impaired and blind students when performing experiments dealing with light. Light sensors can be used with the super-sensitive switch so that the proportional sound could be attained. The apparatus can be arranged so that the sound intensity is relative to the amount of light being sensed. The sensor can also be set up such that a sound is produced when a minimum amount of light is sensed, which is useful in illustrating interference patterns with dark and light bands or the diffraction pattern from a grating.
4. **Multivibrator:** The multivibrator is an adaptation for use with liquids. It emits a sound when its electrodes are placed in ionic solutions, and is useful for qualitatively determining the concentration of solutions and for titrating acids and bases when precipitates are formed.
5. **Oscilloscopes:** Oscilloscopes cannot be directly adapted, because they are designed specifically for a visual output. Some oscilloscopes may have limited audible outputs, usually for indicating the frequency of the waves. In order to give the student an understanding of the frequency and amplitude of the source wave, a vibrator can be connected. The vibrator has a piston that moves vertically depending on the frequency and amplitude of the source wave. A long piece of

fabric elastic stretched between the piston and another stationary object will generate a wave that can be felt, especially if a standing wave is generated.

6. Pendulums: Pendulums, if possible, can be replaced with analog metronomes, as these are designed to emit clicks with every swing and have adjustable lengths. If the student will be using hanging pendulums, then it may be a good idea to use lightweight wire instead of string to suspend the bob. This will allow the student to touch the pendulum lightly at the top to sense the motion, without affecting the swing of the pendulum too severely. Wire will also keep the bob swinging in the proper plane better than string when set in motion by the student, because it will be difficult for the bob to be displaced sideways.
7. pH Meters: pH meters are very useful tools in chemistry laboratories, because the paper indicators are based entirely on color changes. Low vision students may be able to distinguish between very simple red and blue indicators, but the more versatile paper indicators have much more subtle color changes that may be impossible to distinguish for most visually impaired students. On the other hand, electronic pH meters may be easier for visually impaired students to use than paper indicators, and are much more accurate. Some electronic pH meters are available with voice synthesis, but the current models are too inaccurate for use in a laboratory setting, so it is recommended that you use regular electronic pH meters with blind and visually impaired students as well and have a sighted assistant read the output.
8. Raised Line Drawings: Raised line drawing kits and heat-sensitive paper are infinitely useful in the lab. These products are usually used by the teacher or other adapter for preparing materials for the lab such as diagrams and graphs. During the lab, however, the student can draw their own diagrams of their equipment or other results with a manual kit. Graphing is a very important skill and tool for conveying experimental data, and should be accessible to the student. They can either graph manually with a kit, or they could input their data points into a computer program that produces graphs. The computer graphs can then be printed out and transferred onto heat-sensitive paper that will produce raised line graphs of the student's data. The lab partner's results can also be transferred into raised line drawings, if the results from an experiment are visual (magnetic field lines, free body diagrams, etc.), so that the student can interpret the results themselves.
9. Spring Balances: Spring balances are easy to adapt to be read by the student, although they require some time investment. Usually, the scale and pointer are enclosed inside a plastic or metal case. The section of casing above the pointer must be removed. Depending on how deeply the scale is recessed, it may be possible to directly adapt it to be read by touch. More likely, though, the student will not be able to accurately read the original scale, so a tactual scale will have to be etched or added on the side of the casing.
10. Supersensitive Switch: The supersensitive switch which has already been referred above, can be used with a number of types of experiments. It has two contacts that can be connected to electrodes, sensors, or other electrical components, and will emit a sound when the circuit is closed. It cannot be used for titrations, however, as it will continue to emit sound when the solution is neutral because it is more sensitive than the multivibrator. A much simpler version of the super-sensitive switch will work with any conductive solution (including tap water), and is described in the "New Devices" section.
11. Timers: Timers should be relatively simple to adapt. Because the timer already uses a pin to make dots with carbon paper, it can make indentations in the paper

tape as well. A piece of plastic with a small depression would be placed under the paper tape so that the pin can press the paper into the depression. The timer cannot simultaneously use carbon paper, as the carbon paper would be deformed as well, but this adaptation is not permanent so the timer can be used for both sighted and visually impaired students.

Annexure C

Some additional tools

1. **Parchment paper on rubber pad:** Parchment paper is a thin plastic paper. A stylus can be used to draw on this paper when kept on a rubber pad. The drawn figures will appear on the same side as the actual drawing.
2. **Geometry kit:** Geometry kits with tactile markings are available from several sources. This kit helps students to draw geometry figures.
3. **Velcro board:** This is a tool for temporary drawings. A pen with thread is used to draw figures on Velcro board. Figures cannot be stored permanently on this device. Thus, this is excellent to explain concepts to students instantaneously.
4. **SVG draw:** This is a computer application that can be used by persons with blindness to draw graphs and figures. Printouts of drawn figures can be taken out on normal paper or on tactile printer.
5. **Tactile diagrams:** Several technologies such as thermo-forming machines, PIAF machine with swell paper and Braille/tactile figure embossers are being used to create books and study materials for subjects such as Mathematics and Science.
6. **3D models:** 3D models are one of the best ways of teaching concepts to students with blindness or low vision. Models of body parts, birds, animals, chemical compounds etc. are very useful and are being used in all levels of studies including courses on physiotherapy and Chemistry etc. 3D maps, globes, etc. are found to be very useful in teaching subjects such as Geography.
7. **Emprint Color Ink and Braille Embosser:** Emprint is a combined Braille and ink embosser and is an amazing graphical printer for the visually impaired. It can be used for creating graphical drawings for physics, biology, etc.

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