Enhancing Mathematics Instruction for Students with Visual Impairment: A Teacher Training Program on Accessible Online Math

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Abstract: *This research article presents a comprehensive training program designed to enhance the knowledge and skills of lower secondary math teachers in Thailand regarding producing online mathematics materials that cater to visually impaired students. The training program encompassed various topics, including utilizing LaTeX for writing math expressions and equations to facilitate screen readers and adopting vector graphics to ensure scalability for students with low vision. Additionally, the program trained math teachers to create accessible documents, illustrations, videos, web pages, and online tests. A total of 94 lower-secondary math teachers participated in a one-day training session conducted online via Zoom. Pre- and post-training evaluations were conducted to measure participants' knowledge of teaching mathematics to visually impaired students and their attitudes toward accessible mathematics. The evaluations also assessed participants' satisfaction levels and skills acquired from the training program. Statistical analysis revealed a significant improvement in participants' knowledge and attitudes toward accessible math ($p < 0.001$, paired-sample t-test). Furthermore, the findings indicated a high level of participant satisfaction, with an average rating of 4.66 out of 5.00, demonstrating the effectiveness of the training program. Participants strongly agreed that they obtained valuable skills in creating accessible math lessons, as indicated by an average rating of 4.47 out of 5.00. The results highlight the positive impact of taking accessibility factors into account in teaching mathematics online, ultimately fostering an inclusive learning environment for all students.*

1. Introduction

In recent years, the integration of technology in education has opened up new opportunities for online learning environments. Online lessons have been streamlined to be more interactive and engaging with tools that teachers and students can easily access and use. However, while online learning resources have improved for the general student population, there is still a significant gap in accommodating students with visual impairments.

Improving accessibility in other subjects may not be very complicated. Teachers, staff, or volunteers can create audiobooks, braille textbooks, or Word document files that support screen readers. Mathematics, on the other hand, is challenging to enhance accessibility because the subject relies heavily on communicating with expressions, equations, charts, diagrams, and images. In order to enhance the accessibility of online mathematics instruction, it is imperative for educators and media producers to gain a comprehensive understanding of the learning processes employed by visually impaired students, both in offline and online contexts. This entails recognizing the distinctive attributes of accessible mathematical online media and acquiring the necessary knowledge and skills to improve the production of existing and forthcoming online math resources to cater to the needs of visually impaired individuals. Moreover, fostering a positive attitude towards accessible mathematics is of utmost importance, as it serves as a driving force for consistently incorporating accessibility considerations into the development of online math content.

The project aims to increase the knowledge and skills of mathematics teachers in Thailand regarding the production of online mathematics materials that support visually impaired students. Additionally, the project focuses on fostering a positive attitude toward accessible online mathematics that supports all groups of learners, regardless of their visual abilities.

1.1 Visually impaired students and their special needs

The education system in Thailand classifies visually impaired students as blind and low vision [1]. The classification was announced by the Special Education Bureau, Office of the Basic Education Commission to help in manpower and resource planning, as the two groups of learners have different special needs as follows:

Blind students in offline learning contexts – Students use textbooks in braille with symbols to represent expressions and equations [2]. Illustrations, such as graphs, charts, and geometric figures, must be tactile. In addition, teachers must be specially trained to teach blind students.

Blind students in online learning contexts – Students learn from audiobooks and use screen-reading programs, such as NVDA and JAWS, that can read text on-screen aloud (primarily support English). A screen reader can read simple expressions and equations properly if they are in a compatible format, such as LaTeX, MathType, and Microsoft Equation [3]. However, Thai screen readers, such as PPA Tatip, currently do not support reading expressions and equations. Also, braille is inevitable for complex expressions and equations. Illustrations must include alternative text, captions, or descriptions to support screen readers. Videos and demonstrations must have voice narration, or the blind will not be able to learn.

Low-vision students in offline learning contexts – Students use large print [4] (materials with larger text) with high-contrast colors. With normal print, they need to look closer than usual and may need a magnifying glass. Low-vision students are generally able to study with normal students in classes.

Low-vision students in an online learning context – Students use screen magnification to increase their vision. Today's computers and mobile devices often have these functions built in. However, the content must be vectorized or have reasonable resolutions so that it can be enlarged to a certain extent without being pixelated.

1.2 Accessible online math

The blind students relied on lessons they can perceive using other non-visual senses, such as braille, which can be perceived by touch, and screen readers, which can be perceived by hearing [5]. Accessible math designs can be summarized by media type as follows:

Images

Math lessons inevitably require images, be they geometric figures, graphs, or charts. Improving the accessibility of digital images can be done as follows:

Images taken from digital cameras, mobile phones, screenshots, and scanner images are stored as raster graphics. They will be pixelated if enlarged too much. Raster graphics must be taken at a high resolution to be scaled up to a level that people with low vision can see. However, high-resolution images have large file sizes, which can take a long time to download and consume a lot of computational resources. Additionally, text embedded in photos cannot be selected or read by a screen reader.

Math illustrations should be created as vector graphics (such as SVG) so they can be scaled up without pixelation. Plus, they have much smaller file sizes than photos and screenshots. Screen readers can select and read text displayed on vector graphics (if created properly). Current display devices can display vector graphics without problems. Programs and applications like Illustrator and draw.io can provide vector graphics output. Applications like GeoGebra, besides being able to provide vector graphics output, allow teachers to share interactive content for low-vision learners to interact with. Some applications can output 2D and 3D models (such as OBJ and STL) that can be used to create tactile materials for blind learners using UV and 3D printers [6].

No matter how illustrations are created, content publishers need to provide descriptions of those images so that blind people can understand. Adding alternative text (alt text or alt attribute) is one of the most common methods. A screen reader will read alternative text when it reaches where the image is displayed. Additionally, the alternative text will appear if the image fails to load. Various online platforms, especially those used in education, provide alternative text input tools. Some educational platforms do not allow users to publish images without alternative text. For platforms that don't have an alt text tool, designers may add captions or describe the image in body text [7], which is another good practice.

Expressions and equations

Most screen readers can read math expressions and equations properly if they are in a math environment:

- Within Microsoft Equation or MathType blocks, or
- Within TeX or LaTeX delimiters: {math}, {equation}, $...$, $$...$$, \(…\), or \[…\].

Screen readers do not recognize expressions and equations typed using subscripts, superscripts, symbols, or floating text boxes. For example, x^2+2x-5=0 will be read as “x two plus two x, five equals zero” with the minus sign being interpreted as a hyphen. Expressions and equations saved as images require alternative text. Using a suitable mathematical environment, expressions, and equations will be rendered in vector graphics, ensuring scalability for students with low vision.

Documents and web content

A screen reader will recognize images, expressions, and equations in a document file (such as DOCX) and on a web page if they are in appropriate formats, as mentioned above. However, there are other requirements for accessible documents and web content. First, documents and webpages must be outlined using headings so that screen reader users can easily jump to different parts [8]. Numbered and bulleted lists must be created using the appropriate tools or tags so that screen readers recognize them as a sequential list. Most users organize topics using font sizes, colors, line spacing, and manual numbering, which reduces overall accessibility.

Tables in documents and web pages should be used for data presentation only. They should have a simple structure – the first row is a header specifying data in each column, and subsequent rows are corresponding datasets. Sales and transaction records are good examples. Cells should not be merged, and tables should not be used to arrange content. Avoid adding paragraph text to a table.

Blind people typically use the tab key as a shortcut to move to the next content both in documents and on the web. Content designers should ensure that content is presented in the correct order when pressing the tab key [8], especially for images and tables. All images and tables must be "in line with text" (no floating element) to allow the tab key and alt text to work properly.

Converting Word to PDF preserves page formats and most accessibility features, including headings and alt text. Unfortunately, expressions and equations lose screen reader compatibility upon PDF conversion. Getting equations in PDFs back to work with screen readers requires PDF tagging [9], which is a complex process. Therefore, teaching online mathematics to blind students should avoid PDF files.

Web designers and content management systems (CMS) like WordPress typically use MathJax or MathML to render expressions and equations typed in TeX and LaTeX format. These two plugins provide accessibility since they are compatible with screen readers. However, some plugins, such as Elementor with KaTeX, have accessibility issues. In addition, the content layout may differ depending on the device as a result of responsive templates provided by the CMS. Therefore, messages like "from the image shown on the left" should be avoided. Also, hyperlinks should have meaningful display texts, such as "Click to open the image on a new window," to prevent a screen reader from reading the entire URL.

Video content

Video media can present large amounts of information in a short period of time with a combination of motion pictures and sounds. Video materials for the blind must ensure that content is understood by viewers using audio alone. The narrator must explain what is depicted. Saying "from the image shown" or "from the following equation" must be avoided without explaining the image or reading the equation aloud. Video materials with only animations or demonstrations accompanied by background music without audio narration are not available for blind learners.

Web and mobile applications

Web and mobile applications used in education often convert original content into raster graphics and overlay interactive content. Presenting information in that way loses its accessibility properties and causes learning difficulties for visually impaired students. Investigating whether applications are accessible to the visually impaired can be done initially by selecting text and resizing content. If the text is selectable, then the screen reader would work. If the application does not provide a content resize function or the image becomes pixelated when enlarged, it will not support low-vision students.

1.3 Accessibility in the Thai online learning context

Visually impaired students in Thailand do not have much support [10]. Devices like braille displays, braille tablets, UV, and 3D printers are a rarity even in large schools. During the COVID-19 pandemic, a large number of blind students were dropped from the education system as most educational online content does not support screen readers [11]. Therefore, this project emphasizes that the trainee teachers use equipment and free applications both teachers and students can provide. The project organizers were trying to offer a way that doesn't interfere with the original teacher workflow but instead allows teachers to incorporate accessibility features as part of their online math instruction.

2. Related studies

Several studies have explored the development and effectiveness of accessible math learning materials for visually impaired students in online settings. The University of Arizona [12] has created an accessible word problem-solving application for visually impaired students as an iPad app with printed and braille materials. The app contains audio descriptions of images, options to adjust color and contrast, hints, and videos showing sample solutions using Apple's built-in accessibility features, such as Voiceover and Zoom. A study with 29 visually impaired students and their teachers revealed positive results. However, both students and teachers reported different quality of hints and found the video was not very helpful. It has been fixed by adding a video description that shows step-by-step troubleshooting.

It can be seen that text-to-speech is one of the key assistive technologies that support visually impaired students. Online learners typically have access to NVDA and JAWS, famous screen readers. However, one of the issues with screen readers is that they primarily read math expressions and equations in English. Screen readers are often not developed to read mathematical expressions and equations in other languages with distinct pronunciation structures. Screen readers and add-ons that can read math in other languages are in the research and development phase and are not yet widely available. Mahidol University [13] developed an i-Math application that can read expressions and equations in Thai. It was tested on 78 Thai secondary school students with visual impairment (52 blind and 26 people with low vision) and their teachers. The results showed that the developed application was able to pronounce expressions and equations in Thai correctly. Participants found the application useful, especially for visually impaired students who had not learned to write mathematics in braille. However, it has been found that reading aloud may not be effective for complex expressions or equations. A similar application [14] was developed for reading mathematics in Chinese.

Teachers are one of the most important factors in promoting inclusive education. The teacher's role is to understand how visually impaired people learn, especially in math and science, despite their small proportion in class. A case study [15] that interviewed a blind technician was conducted to analyze the factors affecting the learning of visually impaired students. The study found that educational institutions had enough assistive technology for the visually impaired, but teachers lacked the skills needed in special education. Many teachers did not believe in the potential of those learners and did not incorporate accessible media in teaching.

These literature reviews highlight the significance of developing accessible math learning materials, providing comprehensive teacher training, and utilizing appropriate assistive technologies to ensure an inclusive and effective online mathematics education for visually impaired students. Further research in these areas is necessary to continue advancing accessibility practices in mathematics instruction.

3. Methods

This project presented an online training program on creating accessible math materials for visually impaired students in the online learning context. Participants consisted of 94 lower-secondary mathematics teachers in Thailand sampled from 1,481 mathematics teachers in inclusive schools (where normal and visually impaired students study together) listed in the database of the Special Education Bureau, Office of the Basic Education Commission. The number of samples was calculated using the Taro Yamane formula [16] with an error of 10%. The sample was selected according to the proportion of inclusive schools in each region of Thailand.

During the introduction, participants responded to questions regarding knowledge and attitude toward accessible online math in a 5-scale format, in addition to general demographics questions. Materials and instruments have been reviewed by experts in teaching mathematics for the blind.

The instruction phase began by introducing how visually impaired students learn mathematics and the features of online mathematics materials they can learn from. The next part was a guide on how to create teaching materials using online tools that teachers and students can access, as follow:

- Adding alternative text to an image on Word documents, Content Management Systems (e.g., WordPress and Google Sites), and Learning Management Systems (e.g., Moodle, Google Classroom, and Open edX).
- Creating illustrations for math problems in a scalable vector graphics (SVG) format using GeoGebra and Draw.io.
- Introducing the use of colors in diagrams and charts to accommodate the visually impaired.
- Learning how screen readers interact with online math expressions and equations.
- Writing simple math expressions and equations in LaTeX format using CodeCogs.
- Utilizing LaTeX commands on websites and learning management systems, as well as providing alternatives for unsupported platforms.
- Recognizing other elements of accessible documents and web pages, such as headings and tab key navigation.
- Introducing how to narrate in video media to accommodate the visually impaired.
- Practicing creating mathematic quizzes using Microsoft Forms with built-in features for the visually impaired.

The training program was organized online through the Zoom application and lasted for a day. The training material was delivered in web format, which itself acts as an example of accessible online mathematics materials. At the end of the training, participants completed a satisfaction survey and questions about their acquired knowledge and skills, as well as their attitude toward accessible online mathematics. The questions are on a 5-level scale, as shown in Tables 4.1-4.3. Data were analyzed using mean and standard deviation. A paired t-test was used to compare pre- and post-training knowledge and attitude levels.

4. Results

A comparison of the trainees' knowledge before and after the training is shown in Table 4.1. It was found that the trainees didn't have much information about accessible online mathematics materials prior to the training (average at 2.50/5.00). The paired t-test revealed that the trainees had a statistically significant improvement in knowledge at $p < 0.001$.

Table 4.1 Average knowledge of the trainees before and after the training (n=94)

Aspect	Before training	After training
Math online learning of the visually impaired	2.48 (1.37)	4.54 (0.52)
Properties of accessible online mathematics materials	2.53 (1.37)	4.55 (0.54)
Production of accessible online mathematics materials	2.49 (1.36)	4.51 (0.57)
Average	2.50 (1.35)	4.53 (0.49)

Remark: Numbers in parentheses are standard deviations.

A comparison of the attitude of the trainees before and after the training is shown in Table 4.2. It was found that participants were aware of the need for accessible online mathematics materials for visually impaired students (average at 3.66/5.00). Nevertheless, the paired t-test revealed that the trainees had a statistically significant improvement in attitude at $p < 0.001$.

Table 4.2 Average attitude of the trainees before and after the training (n=94)

Aspect	Before training	After training
Online math materials should always be made accessible.	3.66 (1.44)	4.60 (0.54)
Accessible math materials also benefit normal students.	3.62 (1.45)	4.64 (0.48)
Published math materials should meet accessibility standards.	3.70 (1.42)	4.61 (0.55)
Average	3.66 (1.41)	4.61 (0.48)

Remark: Numbers in parentheses are standard deviations.

Table 4.3 shows that the trainees were satisfied with the training program at a "very satisfied" level (4.66/5.00). The trainees were most satisfied with the lecturer's ability to explain concepts, the training format, and the content respectively. Further comments indicated that the training should be conducted in such a way that participants can follow it step-by-step.

Table 4.3 Satisfaction results (n=94)

Aspect	Average	SD
The lecturer	4.73	0.47
The content covered	4.68	0.47
Training materials (website)	4.67	0.47
Question and answer	4.57	0.56
Coordination	4.64	0.53
Duration (one day)	4.64	0.53
Format (online via Zoom)	4.70	0.50
Average	4.66	0.42

The skills acquired by the trainees are shown in Table 4.4 as a result of the self-assessment after the training. The results showed that the trainees had developed skills in producing online mathematics materials that support the visually impaired. They were able to improve existing materials to support the visually impaired and were able to convey the knowledge received.

Table 4.4 Skills acquired through the training (n=94)

Skill acquired	Average	SD
Produce online materials that support the visually impaired.	4.47	0.60
Improve existing materials to support the visually impaired.	4.48	0.62
Convey the knowledge received.	4.46	0.63
Average	4.47	0.59

5. Conclusion and discussion

This project has trained 94 mathematics teachers at a lower-secondary level in Thailand. The aim was to increase the knowledge and skills of teachers regarding the production of online mathematics materials that support visually impaired students. Also, the project aimed to foster a positive attitude toward accessible online mathematics that supports all groups of learners, regardless of their visual abilities.

The data analysis revealed that teachers were less informed about accessible online mathematics and that training programs were effective in providing such information. Training materials created using the proposed techniques are effective in providing information and showing good practices at the same time. Managing online training through the Zoom application is effective enough, considering the results. However, synchronous online training may obstruct the learning of some participants. The project organizer has a plan to create on-demand learning materials that allow participants to practice step by step and pause as needed.

Another aim of the project was to make math teachers aware that producing accessible online math materials does not increase their workload. On the other hand, accessible materials should be viewed as a proper and correct approach so that accessibility factors are taken into account throughout production. For example, teachers can choose whether to use high-contrast solid colors or gradients when creating a graph. One option will work for all learners, while the other will rule out visually impaired students. Also, the "Poor" option won't support any students if the graph is printed in black and white (e.g., for on-site examination). Another example is that many teachers type equations in Word and make screenshots while they can add equations directly to web pages if they use LaTeX commands. This is consistent with [15] that teachers already have access to useful tools. Only teachers put them to good use under the perception that the visually impaired are capable of learning, and the materials that support them are also effective for other learners.

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