

Title	Designing and evaluating an accessible smartphone-based app for blind and visually impaired students for learning mathematics
Authors	Shoaib, Muhammad;Minghim, Rosane;Pitt, Ian
Publication date	2025
Original Citation	Shoaib, M., Minghim, R. and Pitt, I. (2025) 'Designing and evaluating an accessible smartphone-based app for blind and visually impaired students for learning mathematics', INTED 2025 Proceedings, pp. 6954-6961. https://doi.org/10.21125/inted.2025.1787
Type of publication	Conference item;proceedings-article
Link to publisher's version	10.21125/inted.2025.1787
Rights	© 2025, the Authors. Published by International Academy of Technology, Education and Development (IATED).
Download date	2026-10-28 20:21:39
Item downloaded from	https://hdl.handle.net/10468/17222

DESIGNING AND EVALUATING AN ACCESSIBLE SMARTPHONE-BASED APP FOR BLIND AND VISUALLY IMPAIRED STUDENTS FOR LEARNING MATHEMATICS

M. Shoaib, R. Minghim, I. Pitt

University College Cork (IRELAND)

Abstract

The design and development of educational applications to enhance the learning experiences of blind and visually impaired people have improved considerably in recent years. Still, research suggests there is a need for further improvement. Despite the increasing prominence of accessibility features in mobile devices, barriers remain in providing efficient learning resources for these students, especially in STEM topics like mathematics. This paper discusses the design and usability evaluation of AccessMath, a mobile application designed to help blind and visually impaired primary school pupils learn mathematics. The application was developed using accessibility design guidelines, offering adjustable intrinsic brightness, multimodal feedback, a comprehensive settings panel, and intuitive swipe control functions. A usability test was carried out with five blind and visually impaired students employing a variety of metrics, such as task completion time, Usability Metric for User Experience (UMUX), NASA Task Load Index (NASA-TLX), and the System Usability Scale (SUS). The results revealed improved usability, lower cognitive load, and satisfactory user experiences, highlighting the usefulness of the implemented guidelines for designing and developing accessible mobile applications for blind and visually impaired users.

Keywords: Blind, Visually Impaired, Design Guidelines, Mathematics, Education.

1 INTRODUCTION AND BACKGROUND

Mobile technology has changed the way users obtain information and learn new skills. Smartphone apps offer unique opportunities for students to have interactive and personalized learning experiences. However, for blind and visually impaired students, the accessibility of these apps remains a considerable barrier. Traditional mobile apps rely primarily on visual interfaces, which makes them difficult for those with visual impairments to use. This gap in accessibility impedes the educational development of these students, who need more inclusive design approaches.

Accessibility standards like the Web Content Accessibility Guidelines (WCAG) provide a framework for generating accessible digital information [1]. The UXBERT lab introduced ten mobile UX design principles that are important for creating good mobile user experiences [2]. These standards highlight ideas about making content perceivable, operable, understandable, and robust for all users. Although the WCAG guidelines have been instrumental in improving web accessibility, implementing these principles in mobile applications requires extra considerations due to the specific interaction patterns and restrictions of mobile devices [3-4].

Previous studies have highlighted the need for accessible mobile interfaces to fulfill the needs of visually impaired users. For instance, contrast and brightness settings can significantly boost content visibility for individuals with low vision [5]. Multimodal feedback techniques have been shown to improve user interaction and lessen dependency on visual cues [6-7]. Giving users control over interface settings empowers them to modify their experience according to their preferences, increasing their satisfaction and engagement [8]. Intuitive navigation with gesture-based controls can also promote better app browsing for blind and visually impaired users [9].

Despite these features, educational mobile apps lack appropriate mathematics learning materials. Mathematics material provides unique problems for visually impaired learners due to its visual and symbolic nature [10]. Existing solutions typically do not adequately address these problems, resulting in a lack of resources to support efficient mathematical education for these students [11].

This study reviews existing guidelines for accessible application development and seeks to refine and extend them through the development and assessment of a mobile application aimed at helping blind children learn mathematics. We used the refined guidelines to develop AccessMath, which promotes mathematical learning for blind and visually impaired students. We also conducted a usability study with blind and visually impaired individuals in order to analyze the effectiveness of the design decisions and

provide insights into improving accessibility in mobile educational applications. The remaining article is organized into sections addressing various aspects of our research. Section 2 elaborates on the design guidelines for mobile applications. Section 3 provides details about the participants and the methodology used. Section 4 describes the evaluation results of the study, and Section 5 provides information about the discussion and conclusion.

2 OVERVIEW OF EXISTING DESIGN GUIDELINES AND EXTENDING THEM FOR VISUALLY CHALLENGED USERS

We have briefly mentioned the WCAG guidelines and the UXBERT guidelines, which are critical ones with regard to accessible mobile app development. Implementing the WCAG guidelines into our study helps us to benefit from a globally accepted framework that assures comprehensive accessibility. By focusing our design and evaluation on these guidelines, we seek to produce a smartphone application that is compatible with international standards and accessible and simple to operate for blind and visually impaired users. This strategy improves the effectiveness of our work and adds to the more significant objective of making digital materials accessible to all.

2.1 Web Content Accessibility Guidelines (WCAG)

WCAG guideline 1.3 focuses on developing content that may be displayed in numerous ways without losing information or structure. Information, structure, and relationships presented visually should be programmatically determinable or available in text, ensuring interoperability with assistive devices like screen readers. When content sequencing impacts its meaning, the proper order has to be maintained. Instructions should not rely exclusively on sensory features such as shape, size, visual position, orientation, or sound. For example, presenting tabular data like a calendar using speech can cause issues, as individual dates lack context without their matching row or column headings. To alleviate this, developers could give additional context (e.g., announcing 'Friday the 17th' instead of just '17').

WCAG guideline 1.4 emphasizes making it easier for users to see and hear content by correctly separating foreground from background elements and providing audio separation. It highlights that color should not be utilized as the sole visual means of transmitting information, signaling actions, prompting responses, or differentiating visual elements; such dependencies can disadvantage color-blind users or those utilizing monochrome displays. To maintain accessibility, colors should only improve visual appeal or reinforce information supplied through other means. Foreground and background color choices must give sufficient contrast to be immediately distinguishable, which can be tested by examining the material in black and white.

WCAG Guideline 2.1 ensures that each of the features of an application or website needs to be accessible via a keyboard interface. Particularly, it is crucial for blind users who cannot depend on visual cues such as cursor position or other on-screen features and may have difficulty manipulating objects. Interfaces should allow for suitable keyboard navigation—for instance, utilizing the Tab key to navigate among form elements in a logical sequence. It is crucial to avoid creating keyboard traps, circumstances in which a user cannot exit a form field without inputting the necessary information, as this can be very unpleasant and difficult for blind users who may not have access to help text.

WCAG Guideline 2.4 emphasizes providing users with effective ways to navigate and find content. This guideline includes implementing mechanisms that allow users to bypass blocks of content repeated across multiple web pages, such as headers and footers, which can be cumbersome for blind users who rely on screen readers. Each web page should have a descriptive title that clearly reflects its topic or purpose. When content is navigated sequentially, the focus order of interactive elements must preserve the meaning and functionality of the page, ensuring logical and intuitive navigation. Links should be clearly labeled so their purpose is understandable from the link text alone or in conjunction with their programmatically determined context. Proper use of page markup according to standards like HTML5 enables assistive technologies to identify and navigate different sections—such as headers, footers, and navigation bars—allowing users who are blind or visually impaired to skip repetitive content and efficiently locate unique content on the page.

2.2 UXBERT lab Mobile UX Design Principles

The 2nd principle from UXBERT's lab underlines the necessity of making navigation intuitive in mobile app design. A well-designed interface needs to be highly accessible, allowing users to easily navigate around the app without requiring explanations. Users may lack patience and can leave an app if it

requires too much effort or time to find out where to navigate or execute tasks. So, user journeys must be clear and simplified, ensuring that tasks can be completed within the app without needing to hop between pages or other apps. Simplifying processes and having all relevant information easily available keeps people interested.

The 4th principle from UXBERT lab highlights the necessity of offering users control over their interactions in an app. Users value being able to personalize their experiences. Therefore, designers should allow users to make decisions such as altering settings, regulating notifications, and canceling actions. Keeping users informed by adding status updates and feedback to the interface promotes transparency without disrupting their workflow.

The 6th principle from UXBERT's lab stresses the importance of clearly visible interface elements. Since people use their mobile devices in various settings—indoors, outdoors, on public transport, and even in bright sunlight—designs must ensure sufficient contrast between content and background to maintain legibility in any environment. Achieving the right amount of contrast isn't always straightforward, because it needs a comprehensive evaluation of technological guidelines, user diversity, situational factors, and design principles. Designers must balance these aspects to develop interfaces that are both visually attractive and accessible to all users. It's appropriate for designers to consult the W3C's Web Content Accessibility Guidelines for recommended contrast ratios for images and text. Ultimately, the most critical step is to test text and background combinations with users to ensure readability across different conditions.

The 8th principle from UXBERT's lab focuses on minimising data input to optimize the mobile user experience. Typing on tiny screens can be tedious and lead to errors. Therefore, designers should attempt to decrease the necessity of entering information by hand. The desired effect might be achieved through simplifying forms, deleting unnecessary fields, and including 'remember me' choices for future usage. Implementing tools like autocomplete, recent search history, and location awareness can further lower typing needs and speed up interactions.

2.3 Refined Design Guidelines

By refining the design improvements with specific WCAG guidelines and UX design principles, we have strengthened the design of accessible smartphone-based applications for blind and visually impaired users by applying them in practice and then evaluating the usability of the resulting application.

1 Adjustable Intrinsic Brightness for Enhanced Visibility

Incorporate customizable intrinsic brightness settings in mobile applications to improve accessibility for blind and visually impaired students. This allows users to alter brightness levels, improves visual clarity and contrast between text and background, and improves interaction with the application's content. Higher brightness settings can enhance the contrast of text, buttons, and images, making them easier to differentiate for people with limited vision. Additionally, providing alternatives for high-contrast modes and configurable color schemes to cater to the individual needs of users. This strategy aligns with WCAG 1.4 (Distinguishable), which focuses on making content more straightforward by separating foreground from background and supports the UX principle of having interface elements readily identifiable across different environments.

2 Incorporating Multimodal Feedback to Minimize Data Input

Employing multimodal feedback mechanisms in mobile applications by integrating audio cues, tactile feedback, and gestural inputs to offer a more valuable and accessible learning environment for blind and visually impaired students. By offering content using auditory and tactile channels, users can interact with the application more efficiently without relying mainly on visual or extensive data inputs. This lowers the need for typing, which can be onerous on mobile devices, and promotes usability by enabling users to utilize intuitive gestures. This technique aligns with WCAG 1.3 (Adaptable) and WCAG 2.1 (Keyboard Accessible), promoting material that can be displayed in many ways without losing information or structure and assuring all functionality is available through alternative input methods.

3 Empowering Users Through a Comprehensive Settings Panel

Offering a comprehensive settings panel inside the mobile application to give users complete control over its function and appearance. Allowing users to personalize their experience by adapting settings such as speech speed, volume control, color contrast, text size, and notification preferences—not only promotes accessibility but also empowers users with a sense of

independence and transparency. This correlates with the UX principle of enabling user control, ensuring that users may adjust the app to their unique needs and preferences.

4 Implementing Swipe Controls for Intuitive Navigation

Providing simple swipe control functionalities and standard gesture-based navigation within the smartphone application enables a simple and predictable way for visually impaired students to explore the app. Utilizing consistent swipe moves helps users to apply learned controls across various applications, reducing the learning curve and improving usability. Providing tactile interaction options minimizes the need for visual cues, enabling visually impaired students to explore the application independently and confidently. This empowerment correlates with WCAG 2.4 (Navigable), which offers means to assist users in navigation and finding content and supports the UX principles of making navigation intuitive.

3 METHODOLOGY

3.1 Design and Development of AccessMath [12]

The AccessMath app was designed to focus on four essential accessibility features: changeable intrinsic brightness, multimodal feedback, user settings panel, and swipe controls. These features enable them to better use their visual skills by changing brightness and contrast to minimize dependency on visual information by audio cues. Auditory and vibro feedback for output and gestural inputs help them navigate the app easily. With the help of a user-controlled setting panel, users can customize the app extensively to their preferences.

3.2 Usability Evaluation

A usability test was conducted with five blind and visually impaired users to examine the app's usability, cognitive load, and user experience. The study utilized measurements, i.e., task completion time to measure efficiency, the UMUX for perceived usability, NASA-TLX to evaluate cognitive workload, and the SUS for overall user satisfaction. Participants interacted with the app to perform the task and access the mathematical information. Later, they provided valuable feedback on the effectiveness and accessibility features of the application.

3.3 Participant Information

Five blind and visually impaired students were involved in this study, two males and three females. Their ages ranged from 9 to 12 years. All students had experience using mobile applications with assistive features. Ethical considerations were observed carefully, and all students were given informed consent before the study. This study has highlighted the Usability Evaluation. First, it expands existing accessibility guidelines to better suit the mobile context for blind and visually impaired users. Second, it presents empirical information on the usability and user experience of AccessMath, giving valuable insights for developers and researchers in accessible educational technology. Table 1 offers comprehensive details about each participant.

Table 1. Demographic information of the Users

<i>User ID</i>	<i>Age</i>	<i>Gender</i>	<i>Type</i>
U1	12	Female	Blind
U2	10	Male	Blind
U3	11	Female	Low Vision
U4	9	Male	Blind
U5	12	Female	Low Vision

4 RESULTS

A task was designed, and each participant was asked to draw the geometrical shapes, i.e., "Click on the app Icon," "Swipe down for Shapes and Digits," "Swipe up for Geometry Shapes," "Draw the shape," "Speak out correct/wrong Answer" "Double tap for repeat" and "Triple tap for application quit". Auditory feedback was provided for each activity performed by the participant. Speech feedback alerted users if

they made errors. Each participant completed the task three times, with a maximum allotted time of 150 seconds per task. The mean task completion times for participants ranged between 130 to 148 seconds, indicating that all participants were able to complete the tasks within the required time. However, the variation in completion times suggests that some participants may have found certain aspects of the task more challenging than others. Figure 1 outlines the task completion time of each participant.



Figure 1. The task completion time of the participants

The UMUX scores for the participants ranged from 75.0 to 91.67, with an average score of 83.33. This score indicates high perceived usability. A score above 80 on the UMUX scale reflects that participants generally found the system easy to use and capable of meeting their needs, which correlates with a positive user experience. Figure 2. illustrates the UMUX (Usability Metric for User Experience) score of each of the participants.

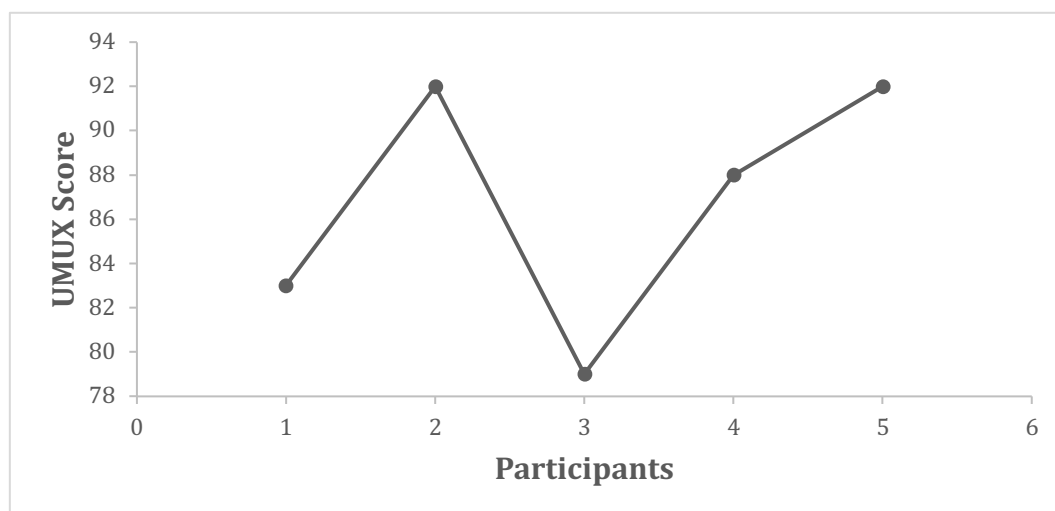


Figure 2. The UMUX (Usability Metric for User Experience) score of the participants

The NASA-TLX measures the perceived workload across six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration. The average workload score across all participants was 49.83, indicating a moderate perceived workload. Some participants reported high mental demand, effort, and frustration, especially during complex or time-sensitive tasks. Figure 3. demonstrates the participants' NASA Task Load Index (NASA-TLX) scores.

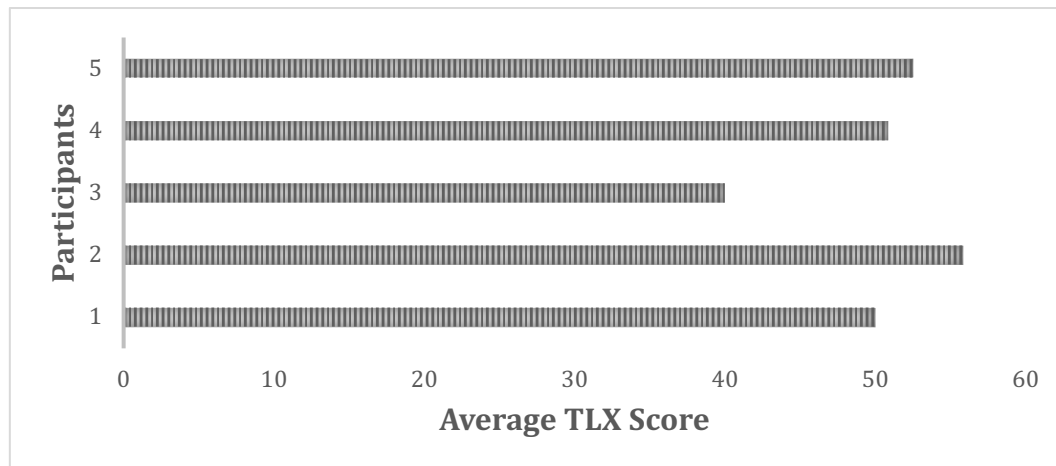


Figure 3. Demonstrated the NASA Task Load Index (NASA-TLX) score of the participants

The SUS scores ranged from 75.0 to 92.5, with an average score of 83.5. A score above 80 counts as excellent, indicating that users found the application highly usable. Many participants evaluated the application positively, believing in their ability to learn and manage it quickly while seeing that it was not excessively complex or challenging. Figure 4. shows the System Usability Scale (SUS) scores of the participants.

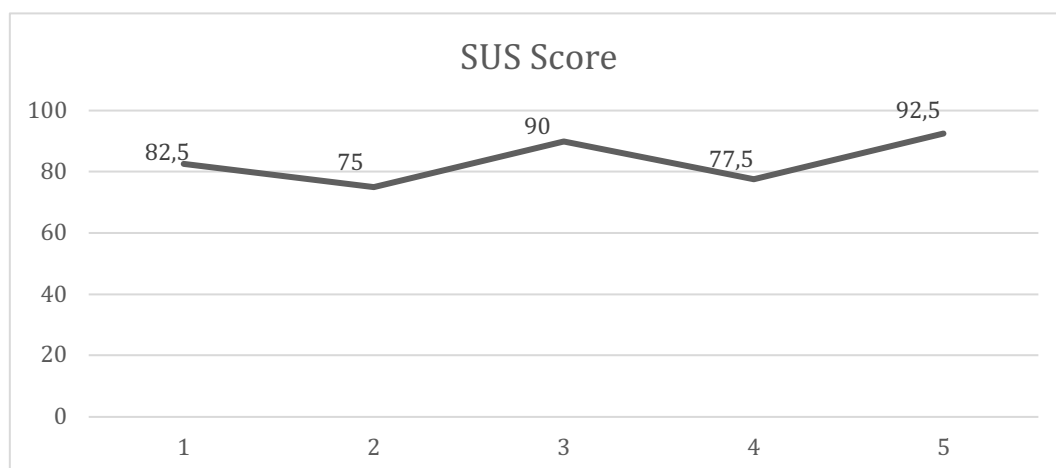


Figure 4. Shown the System Usability Scale (SUS) score of the participants.

5 DISCUSSION AND CONCLUSION

The development and evaluation of AccessMath illustrate the usefulness of implementing specific accessibility guidelines in the design of an app for blind and visually impaired users. The positive usability evaluation results suggest that features like user-selectable brightness, multimodal feedback, user-controlled settings, and clear swipe navigation greatly enhance the user experience.

The work described here highlights the value of extending existing guidelines, expands the knowledge of accessible mobile application design, and provides practical guidance for developers hoping to develop inclusive educational tools. By integrating our extended design guidelines with specific WCAG principles and UX design concepts, we strengthened the importance and usefulness of our suggestions for creating accessible mobile apps for blind and visually impaired users. In particular, we looked at WCAG guidelines concerning: brightness and contrast settings, with the help of intrinsic brightness, to create more distinguishable content (1.4 Distinguishable); including multimodal feedback like audio and tactile cues to make content adaptable (1.3 Adaptable); guaranteeing all functionalities are accessible using alternative input methods like introducing gestural controls (2.1 Keyboard Accessible); and introducing simple swipe gestures to enhance navigability (2.4 Navigable). Consequently, we adopted UX principles by improving visibility through customized brightness and contrast, decreasing data input

requirements through gesture controls, empowering users through a customizable settings panel, and permitting simple and predictable navigation using intuitive swipe gestures.

Furthermore, during the evaluation, the task completion times reveal that the application is accessible and effective for blind and visually impaired users. Slight differences in intervals during usability testing could indicate specific usability changes that may help to minimize cognitive or operational pressure for some users. The UMUX scores imply that the smartphone app is well-received in terms of usability, with users perceiving it as beneficial, simple to use, and effective in helping them achieve their tasks. Furthermore, the moderate workload scores signal that while the technology is helpful, certain aspects may inflict cognitive and emotional pressure on users. Efforts to streamline task workflows, simplify interactions, or lessen physical and mental demands might reduce workload and improve user satisfaction. Finally, the SUS scores coincide with the favorable UMUX findings, demonstrating that users consider the smartphone application intuitive and effective. An overall SUS score of 83.5 shows that the application provides a solid user experience, while a few minor changes in areas such as consistency or support might further boost usability.

ACKNOWLEDGEMENTS

This publication has emanated from research conducted with the financial support of Science Foundation Ireland under Grant number 18/CRT/6222. For the purpose of Open Access, the author has applied a CC BY public copyright license to any Author Accepted Manuscript version arising from this submission.

REFERENCES

- [1] World Wide Web Consortium (W3C). (2018). Web Content Accessibility Guidelines (WCAG) 2.1. Retrieved from <https://www.w3.org/TR/WCAG21/>
- [2] 10 Mobile UX Design Principles You Should Know (2017). UXBERT Lab. Retrieved from <https://uxbert.com/10-mobile-ux-design-principles/>
- [3] Vigo, M., Brown, J., & Conway, V. (2013). Benchmarking web accessibility evaluation tools: Measuring the harm of sole reliance on automated tests. Proceedings of the 10th International Cross-Disciplinary Conference on Web Accessibility (W4A), 1-10.
- [4] Power, C., Freire, A., Petrie, H., & Swallow, D. (2012). Guidelines are only half of the story: Accessibility problems encountered by blind users on the web. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 433-442.
- [5] Kane, S. K., Bigham, J. P., & Wobbrock, J. O. (2008). Slide rule: Making mobile touch screens accessible to blind people using multi-touch interaction techniques. Proceedings of the 10th International ACM SIGACCESS Conference on Computers and Accessibility, 73-80.
- [6] Giudice, N. A., Palani, H. P., Brenner, E., & Kramer, K. M. (2012). Learning non-visual graphical information using a touch-based vibro-audio interface. Proceedings of the 14th International ACM SIGACCESS Conference on Computers and Accessibility, 103-110.
- [7] Yu, W., Ramloll, R., & Brewster, S. (2001). Haptic graphs for blind computer users. Adjunct Proceedings of HCI International, 1-4.
- [8] Yesilada, Y., Harper, S., & Goble, C. (2004). Disabled users and the library: Accessibility of library services and resources to visually impaired users. Proceedings of the 6th International ACM SIGACCESS Conference on Computers and Accessibility, 169-176.
- [9] Branje, C., Marshall, S., & Ju, W. (2014). Integrating haptic feedback into mobile touchscreens. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 1-4.
- [10] Jayant, C., Acuario, V., Johnson, W., Hollier, J., & Ladner, R. E. (2010). V-braille: Haptic braille perception using a touch-screen and vibration on mobile phones. Proceedings of the 12th International ACM SIGACCESS Conference on Computers and Accessibility, 295-296.
- [11] Buzzi, M. C., Buzzi, M., Leporini, B., & Mori, G. (2011). Designing mobile applications for blind users. Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services, 73-77.

- [12] Shoaib, M., Minghim, R., Fitzpatrick, D., & Pitt, I. (2024, June). Accessmath: Towards Developing an Accessible Interactive Learning Platform to Overcome the Challenges of Blind and Visually Impaired Students in Learning Mathematics. In International Conference on Human-Computer Interaction (pp. 174-184). Cham: Springer Nature Switzerland. References