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AccessMath: Towards developing an accessible interactive learning platform to overcome the Challenges of blind and visually impaired students in learning mathematics

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Abstract. Smartphone-based apps and games can provide an enjoyable and inspiring atmosphere for learning mathematics. They potentially offer an engaging and exciting way to help students utilize their previously acquired abilities. Implementing such platforms has become increasingly significant in the rapidly evolving educational technology landscape. However, the integration of such technologies poses unique challenges and opportunities, particularly when it comes to catering to the needs of blind and visually impaired primary school students. This article is based upon a survey designed to investigate the needs of blind and visually impaired students and identify enablers that improve the effectiveness of interactive learning platforms specifically for learning mathematics. Nineteen people participated in this study: five blind and visually impaired students, nine teachers, and five professional experts. Participants highlighted important functionalities which would help them address their needs in primary education settings. Using the findings from this study, the authors aim to develop an interactive learning game to fulfill the participants' needs. This interactive game focuses on enhancing numbering skills, performing basic mathematics operations, and learning about shapes and digits because most school children struggle to learn these topics. This game can engage blind and visually impaired students and help them quickly understand these topics. The aim has been to introduce educational aspects in a way that does not compromise game enjoyment.

Keywords: Smartphone, Interactive, Learning, Mathematics, Blind and Visually-Impaired.

1 Introduction

The popularity of smartphones and other mobile devices in our daily lives keeps increasing. These devices add novel features with each new version, improving ease and affordability. New applications are regularly developed to simplify numerous aspects

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of our lives. This technological advancement has motivated researchers and developers to take advantage of these devices within the educational sector to move from traditional classrooms to more dynamic and engaging learning environments [1]. It allows teachers to educate students without being confined by location or time. It also encourages learning inside and outside the classroom, during or after classes [2]. These devices also allow teachers to interact with their students more efficiently and enhance their student's concept-building [3]. Chiong and Shuler analyzed the impact of smart mobile devices and their applications on preschool- and early-elementary-aged children. They found that children can use these devices easily, and the apps can boost their learning skills[4].

Based on these and similar findings, the idea of developing a learning game has emerged. Educational games entertain students and help them learn several subjects, including mathematics. Mathematics is compulsory for primary school students in Ireland and many other countries. This subject is constructive for developing problem-solving skills in students, but sometimes it's very confusing and challenging [5]. Blind and visually impaired students face particular challenges when accessing visual mathematics content, i.e., graphs, formulas, and mathematical notations. The UN Convention on the Rights of Persons with Disabilities states that persons with visual disabilities should not be overlooked or left behind in terms of quality of life [6]. Similarly, the World Health Organization requires that implementation of its Sustainable Development Goals "leaves no one behind", including those with a visual disability [7].

The continual improvement in digital assistive technologies offers novel opportunities to overcome many barriers faced by people with visual disability. Smartphones are one of them, and they include several accessible features and applications for blind and visually impaired students. For example, MathMelodies is an iPad application developed for primary school students, including those with vision difficulties. The developers examined the problems that occur during the design of an accessible learning environment by using a user-centered design. They evaluated the usability of this application with professionals, blind students, and sighted students. They found that inclusion of object-based interactions, audio cues, and text-to-speech enhanced user engagement. [9]. AudioMath, introduced by Jaime and Hector, is another example. It supports blind children in learning mathematics using audio-based interactions. The developers focused on improving short-term memory and arithmetic knowledge using an interactive auditory interface. The application was built with input from blind students and was tested for its efficiency in increasing memorization and learning skills. The study reveals that audio can be a powerful aid for boosting memory and learning maths in visually impaired children [10]. Further examples are discussed in Section 2.

This article is based upon a study conducted among domain experts, teachers, and blind and visually impaired students in order to identify design guidelines for developing an accessible solution for learning mathematics. This research aims to design and develop a mobile-device-based mathematics learning game called AccesMath. Students can use this learning application from anywhere. Using and playing this game can enhance the

children's understanding of mathematics. The remainder of this article is organized as follows: Section 2 explains the related work; Section 3 illustrates the study's procedures; Section 4 describes the proposed learning game architecture; Section 5 provides the participants' comments and information; Section 5 concludes this article and provides recommendations for future work.

2 Related work

Previous research has revealed several software tools available for blind and visually impaired students to access mathematical content. Mejia et al. provided an extensive survey of software tools available for visually impaired persons to access, create, and manipulate mathematical material. They analyzed the issues visually impaired persons faced when accessing mathematical resources. They categorized the tools into two groups: those for accessing mathematical content and those that enable them to execute mathematical operations. The report also examined the advantages and disadvantages of essential technologies for interacting with mathematics material [11]. Audio Games [12] was a novel technique that analyzed the impact of audio games on visually impaired individuals' learning and cognitive skills development. They showed how audio-based teaching aids and combining user-centered design can significantly boost visual representation, memory, and problem-solving skills among blind students. The research evaluated the audio games developed for teaching, focusing on the potential for improving learning skills in blind and visually impaired learners. Shoiab et al. [13] investigated the development of a mobile e-learning application designed to aid visually impaired children in learning basic mathematics. The aim of the research was to enhance smartphone application accessibility through a user-centered design approach. The study focussed on a prototype application that was modified in the light of user feedback. The modified version yielded reduced task completion time and greater user satisfaction. The modifications were designed to simplify navigation, improve color contrast, and provide more rapid feedback, and user testing confirmed the usefulness and reliability of the application for visually impaired students.

Song et al. [14] examined the design and execution of mobile learning games for visually challenged children. They focused on increasing spatial skills using two audio mobile games: "Cardinal Direction and a modified Tower of London". The study comprised both quantitative and qualitative evaluation, with results indicating enhanced enjoyment among participants. The results provided insights into building more efficient and interactive smartphone games for visually impaired users. Sánchez and Sáenz [15] analyzed the usage of "The Natomy's Journey Games" an audio-based video game. It demonstrated the game's design and implementation by emphasizing an interactive environment among blind and sighted students. The study examined the game's accessibility and its influence on integrating blind students into mainstream classrooms, highlighting considerable improvements regarding learning and integration into society. Arlinwibowo et al. [16] focused on constructing an Android application to aid visually impaired students in learning mathematics. The project involved specialists from

several sectors to produce a realistic, feasible, and practical app. They highlight the need to establish accessible educational technologies that respond to the special needs of blind and visually impaired students, enhancing their capacity to learn and test skills effectively. Ramos et al. [17] discussed two case studies employing gamification approaches for blind and autistic individuals. The first study offers an application teaching Mexican currency to blind persons using interactive interfaces and gamification. The second study explored an app for autistic children, enabling them to better navigate and engage through a virtual reality game. Both studies indicated the beneficial use of technology and gaming in teaching for those with disabilities.

3 The Procedure of the Study

This research study was carried out with blind and visually impaired students, teachers, and professionals working in accessibility. A group of nineteen users took part in the research, including five blind and visually impaired students, nine teachers, and five domain specialists. The thirteen female and six male participants in this study were 9 to 58 years old. The research was organized in two phases. In the first phase, we conducted a study with students, teachers, and domain experts to explore several themes. In the second phase, we gathered their opinions and suggestions for developing a smartphone-based accessible solution. Table 1 offers comprehensive details about each participant.

Table 1. Demographic information of the Users

User ID	Age	Gender	Type
U1	12	Female	Student
U2	10	Male	Student
U3	11	Female	Student
U4	9	Male	Student
U5	12	Female	Student
U6	52	Female	Teacher
U7	42	Female	Teacher
U8	26	Female	Teacher
U9	29	Female	Teacher
U10	45	Male	Teacher
U11	37	Male	Teacher
U12	43	Female	Teacher
U13	54	Female	Teacher
U14	44	Female	Teacher
U15	43	Female	Professional
U16	58	Male	Professional
U17	40	Male	Professional
U18	57	Female	Professional
U19	41	Female	Professional

3.1 The interviews for this study

The study was conducted from August to November 2023, and interviews were conducted via video call (on Teams). The semi-structured interviews were conducted with students, teachers, and domain experts. Most questions were open-ended, allowing participants to explore the topic comprehensively. Towards the end, participants had the chance to express any views they felt were not addressed during the interview.

3.2 The analysis process and general findings

From the collected interview data, we have explored the challenges of blind and visually impaired students and the experiences of teachers and experts. Using thematic analysis, we identified several essential themes, i.e., "Mathematics Topics," "Challenges, Obstacles, and Issues", "Digital and Non-digital Resources", and "Ways to make learning mathematics easy" etc. A full description of the study and the thematic analysis will be published as a separate paper. Moreover, information was gathered from blind and visually impaired students about what kind of applications might help them to learn mathematics. The opinions of teachers and domain experts regarding the design of smartphone-based solutions for these students were also noted. This article focuses on the design guidelines for an accessible solution resulting from the study i.e., independence, font and color contrast, proper labeling, clear navigation, etc. These guidelines were used in the design of a game called "AccessMath".

3.3 Ethical Considerations

Permission was obtained from the University, school management, and the participants for the conduct of this study. All participants were given an information sheet and fully briefed on the study's purposes. All participants signed informed consent forms. They were told that the entire experiment would be recorded for evaluation purposes. The respondents were assured that no harm was involved either before their participation or during the study to extract information. It was emphasized that the participant's involvement in the study was voluntary. Additionally, the participants received assurances about the confidentiality of their identity, with explicit instruction that real names and addresses would not be used in the final report. To uphold ethical standards, we followed the guidelines outlined by Bogdan and Biklen [18], encompassing informed consent and protecting participants from any potential psychological harm or danger.

4 Proposed Learning Game (AccessMath)

This study highlighted essential guidelines and opportunities for developers: independence, font and color contrast, proper labeling and clear navigation, multimodal approach, easy access, and no internet dependency. See below the details about these guidelines:

Independence: Support blind and visually impaired students to work without supervision. Provide them with straightforward game rules and motivate them with the game's entertainment factor that can keep them focused on the task.

Font and color contrast: Make it easy for them to adjust font size and color contrast based on their needs.
Proper labeling and clear navigation: Ensure proper labeling of the interface elements, i.e., buttons, etc., and clear navigation between screens to make the app more accessible.
Multimodal approach: Make appropriate use of text-to-speech, vibro-tactile, and auditory feedback.
Easy access: Students should be able to access and use the app from anywhere. It also refers to obtaining the app (e.g., free of charge, simple download and installation).
No Internet dependency: Students should be able to use the app without Internet availability.

Subsequently, we applied these recommendations and guidelines in developing a game named AccessMath to help the blind and visually impaired. This game has three main modules named "Basic Operations", "Shapes and Digits," and "Numbering". There details are mentioned below:

Basic operations: Through interactive challenges, the game presents addition, subtraction, multiplication, and division concepts to blind and visually impaired students. We have utilized audio narratives, swipe functions, audio, and vibro feedback. Students can solve the questions and learn more about basic operations using them.
Shapes and digits: Using a multimodal approach, teach geometry shapes, lines, symbols, and digits drawing to blind and visually impaired students. Users can draw the shapes by touching the screen, and audio explanations illustrate them more appropriately for them. It can be useful for designing games where players can recognize and classify shapes using their touch and auditory perception.
Numbering: Start with basic counting activities using auditory cues for numbers where blind and visually impaired users can learn counting skills. Also, introduce a comparison of numbers using sound-based activities that could help them in learning.

Figure 1 presents a detailed overview of our proposed game. All these activities are interactive, engaging, and accessible for blind and visually impaired students. Frequent feedback, encouragement, and progressively challenging levels can enhance their learning experience.

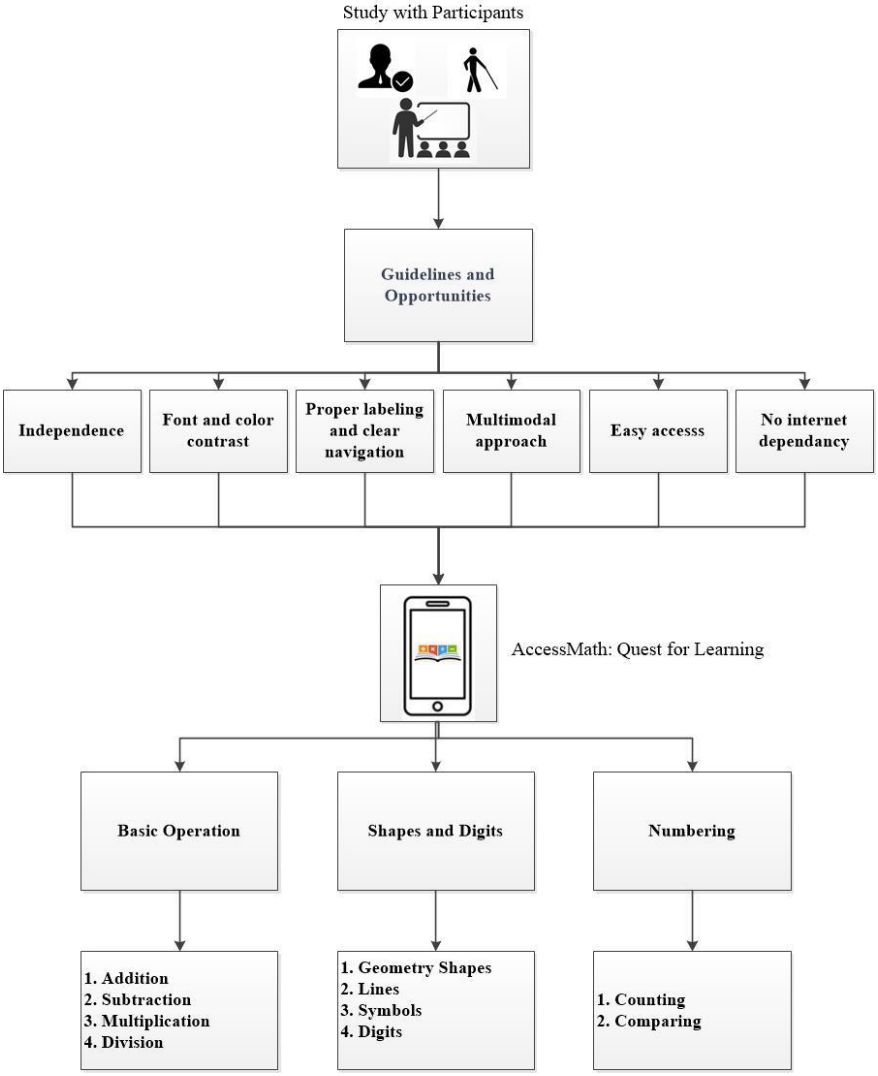


Fig. 1. Proposed methodology for this research study

5 Interesting guidelines/suggestions/opportunities suggested by participants.

As described above, the study comprised two parts. The first part involved a thematic analysis of survey results concerning inclusive learning. The second part focused on the design of an inclusive learning platform, and some of the resulting guidelines and suggestions for researchers and developers are listed below:

"Blind and visually impaired students like games. But for my blind students, unless somebody sits beside them all the time and explains exactly what's happening in the game or helps them manage it. So, I think the independence of students is essential."
"Games can be quite useful because using them on the tablet or other mobile device makes students happy. They can use screens if the interface elements and fonts of the apps are big enough to see."
"Measuring skills-based solutions and devices we need. Some of these resources are available in America but not in Ireland. England is also making resources that will make measuring more accessible."
"I think a possible solution might be something like preparation for leaving CERT. Students can prepare math for Leaving Cert with the help of a learning app, which helps them learn different topics like measuring and graphs."
"Anything they will do with speech and students can use from anywhere."
"There were a lot of topics that they could learn through playing games like understanding the numbers and quantity of numbers, graphs, basic math operations etc."
"For a developer developing a tool to support them, I think the first thing is to use co-design, so they have to work with these people to have live experience. For example, if you are working with students, try to recruit one or two nine-year-old students to be a part of your team; I think they'd take great pride and ownership, and they really appreciate being invited onto something like that to be a part of building the solutions to support themselves."
"The best platform all depends on the end users. You know what I mean? And it depends on what's available to them. So a lot of them will have smartphones, but maybe what you're building is not going to necessarily if it's in this classroom environment, you know, smartphones and now being banned everywhere and all this kind of stuff, especially if it's a mainstream classroom and the school of no bond smartphones, it kind of rules out the opportunity of having that tool on the smartphone, which is a bit crazy. I think the smartphone is the most accessible as it's the one the kids will engage in the most, but this is good for their home. If you're actually talking practicality, I'd probably go down the tablet route, as in that's what if you look at the broader scale of things, if you look at how like big screens, how they will work really well and integrate really well with systems, I think a lot of that is built for tablets. If it's something that's actually going to be educational, then a tablet could be a good choice."
"If the audience is primary school kids, then gamification will be really important, and games will be a motivation. Another thing, it's better that the game does not have internet dependency. And if it's an older cohort of students like secondary school students who are just trying to pass the Leaving Cert, they will have a different motivation. And so, in their case, it will be the laptop because when they walk into that leaving CERT exam, it's a laptop they will be in front of."
"If you are designing a solution, you must see the curriculum. Considering the end users like the persons with the disability and their needs, his teachers, and his family members views."
"I think taking a universal approach to learning is really important, and using a multimodal approach to integrate the solution is more beneficial if possible."

"The work we're finding on sites is to do with poorly labeled or unlabeled things. Developers should avoid this; proper labeling, clear navigation, and color contrast matter a lot."
"I've heard about games and even the VR experiences where you can learn about different subjects. VR-based solutions could help people in their learning."
"During the planning stage of an app, you should engage with the audience. Also, it's important to include people with disability in the research."
"I suppose providing audio and vibro feedback to understand the number sequence, numbering lines, 1, 2, 5, getting vibrational feedback on doing something, even moving from one cell to another, anything like that will help them."
"I have never used a screen reader. I like easy things that I can easily access and use from anywhere, for example, a scanning pen; I want to scan text, giving me audio information about this. So, it is something that gives me information in voice, or I can learn it through play again. Something provides me with feedback in speech and vibration, I like it."

6 Conclusion and future work

Educational and assistive technology are evolving day by day. Because of this, providing equal opportunity for learning for blind and visually impaired primary school students is very important. We have conducted a study with blind and visually impaired students, their teachers, and domain experts to introduce an inclusive learning solution for them. The results of this study illustrated that providing them with an independent learning environment, proper opportunities for font and color contrast settings, adequate labeling of user interface elements, straightforward navigation between screens, the introduction of a multimodal approach, easy access to the learning platform, and running of the application without internet dependency can make the solution more accessible for them.

We have developed a learning game, "AccesMath", for these students by keeping these guidelines in mind. This math learning game provides inclusive education for blind and visually impaired primary school students. This game involves basic mathematical operations, shapes and digits, and numbering skills. Our game consists of special accessibility features by keeping a range of learning requirements in mind and considering the influence of mobile devices on blind and visually impaired student's educational experience. We have attempted to understand the nature of learning for blind and visually impaired students and to develop an interactive and user-friendly platform. This platform introduced a multimodal approach for feedback and user setting based on their needs that enhance the accessibility nature of this app. In a follow-up study, we plan to investigate the usefulness and effectiveness of this mobile application for the learning enhancement of blind and visually impaired students. We will examine whether blind and visually impaired students use this to improve their learning skills.

Future researchers can introduce machine learning-based algorithms that customize the game to each player's learning preferences and skill level. These customizations could be based on each student's strengths and weaknesses. Furthermore, the game's features could be expanded to include more complex topics appropriate for elementary school grades. This expansion might cover more advanced geometric shapes, fractions, and decimals, offering a more extensive mathematical education. Moreover, we suggest that researchers and developers should work together with experts and organizations that specialize in accessibility to carry out comprehensive studies on the efficacy of the game in various educational settings. Maximizing the game's impact and obtaining insights might involve collaborating with academic institutions, accessibility specialists, and teachers. Finally, we should explore other ways to use the game to involve parents in their children's education and provide them with possibilities to engage in educational opportunities at home with their children.

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