Towards Devising a Low-cost and Easy-to-use Arithmetic Learning Tool for Economically Less-privileged Visually-impaired Children

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Abstract

Basic arithmetic operations such as addition, subtraction, multiplication, and division are essential skills needed in our life. This is no different for the people with visual impairment. Although mental arithmetic is an asset for both sighted and non-sighted people, arithmetic workout in a paper context is a challenge for visually-impaired people. The situation is exacerbated by the low-resource settings of developing regions due to the paucity of low-cost and easy-to-use solutions. In this study, we present challenges faced by the visually-impaired children of Bangladesh, a developing country, in their arithmetic education. We propose a low-cost and easy-to-use solution to these challenges and draw a contrast between the conventional means of solving arithmetic problems and our proposed solution. We believe that this study will help breaking barriers to similar challenges situated in other developing regions across the border.

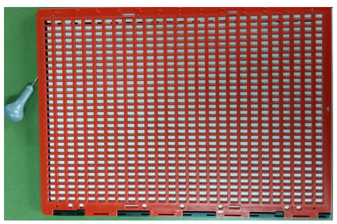
Author Keywords

Assistive technology; Visual impairment; Low-resource settings; Arithmetic education

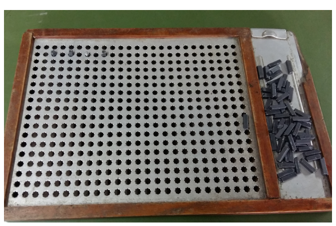
Introduction

Arithmetic is taught in the early stages of education as a prerequisite to solve hierarchically complex mathematical problems. School children are thus taught single digit basic arithmetic skills such as addition, subtraction, division, and

Figure 1: Mathematics book for Class 5



(a) Braille writing frame



(b) Arithmetic solving frame tool

Figure 2: Tools used by visually-impaired children while solving math problems

multiplication [12]. Children with visual impairment are also taught arithmetic skills at their early age.

The conventional form of teaching mathematics to visually-impaired children is the Nemeth Braille code [1]. This encoding leverages the conventional Braille framework to represent mathematical and scientific notations. Conventional Braille is apparently considered difficult since it takes extra efforts to learn [11]. In addition, the surging popularity of smartphones and other electronic devices have made Braille less popular among the developed nations [2, 10]. A study in [7] discusses about the issues and teaching techniques of imparting mathematics to the visually-impaired people. It also emphasized that much of learning mathematics is heavily dependent on visual reference. Some other state-of-the-art technologies assisting visually-impaired people in counting, such as talking calculator, tactile graphing boards, etc., are also discussed in the study. The study in [8] discusses about two types of visual-spatial representation of mathematical problems. Besides, AudioMath is a short-term memory and mathematics learning tool utilizing auditory senses [15].

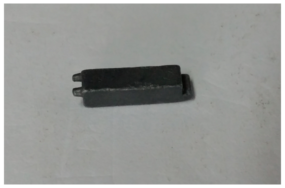
However, some recent studies relate that Braille is still popular among developing countries, particularly because, people from developing regions are less likely to get benefited from expensive high-end technological devices [5, 6]. Studies such as [9], however, presents why Braille has limitations in terms of mathematics education. Despite such limitations, it has also been found that Braille literacy is highly important for employment purpose [13, 14]. Moreover, a recent study [3] also points that Braille exhibits utmost significance pertinent to mathematical education for the visually-impaired people.

To this end, a couple of facts motivates us to investigate state-of-the-art education systems for visually-impaired children from low-income countries. First, the World Health Organization (WHO) reports that approximately 285 million people are visually-impaired world wide [4] and 90% of this population live in low-income settings [4]. Second, a study [16] shows that youth with visual impairment are more likely to complete school and go to college, and even likely to complete post-secondary education. In this study, we take aim at understanding existing method of mathematics education, particularly arithmetic, in Bangladesh as a representative of low-income countries. As a remedy to the problems revealed by this study, we propose a practicable and convenient arithmetic learning tool for visually-impaired children. This tool leverages a low-cost Braille reading and writing framework presented in our prior work [6].

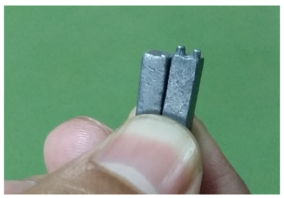
Research Context

Our study was conducted at the National Foundation for Betterment of the Disabled at Mirpur, Dhaka. This is a government run organization that supports education and rehabilitation program for disabilities such as visual impairment, deaf or hearing impairment, autism spectrum disorder, etc. The school for the visually-impaired children is run by ten teachers. The medium of instruction in this school is Bengali. Similar to regular school curriculum, visually-impaired children are taught regular subjects, such as Bengali, English, Mathematics, Religion, etc. Students are taught Braille in the early stages of their education. The school is heavily subsidized by the government. Students are given the yearly academic books at the start of the year. This supply comes from the only government-run Braille printing press.Figure 1 shows a snapshot of palpable Braille printed mathematics book for Class 5.

Figure 2 shows the regular tools used by the visually-impaired children while solving mathematical problems. The tool in Figure 2a is used for writing in Braille. It has 30 small cells



(a) Lead bar



(b) Comparison between a used lead bar and new lead bar

Figure 3: Lead bar used in the arithmetic tool

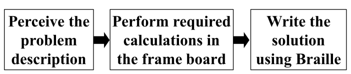


Figure 4: Flow digram of existing method for arithmetic problem solving

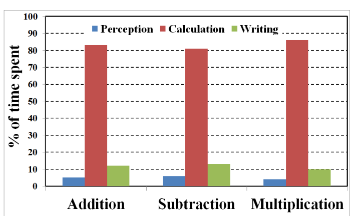


Figure 5: Percentage of time taken in different steps of arithmetic problem solving

Participant	Category	Age (years)	Class
P1	Blind	10	4
P2	Low vision	10	4
P3	Low vision	11	5
P4	Blind	12	5
P5	Low vision	14	5

Table 1: Demography of participants

containing six small notches for six Braille dots. The tool in Figure 2 is the arithmetic frame. They primarily use this frame to solve calculation problems such as addition, subtraction, multiplication, and division. The frame has 18 rows with 25 holes in each row. A small lead bar is inserted in each hole and appropriate notches resembling different orientations to enumerate different single digit numbers. Figure 3a shows a lead bar sample used for this purpose. Both ends of this lead bar have differently shaped ridges depicting two different sets of information. Visually-impaired children discern these ridges or jagged tips exploiting the haptic senses. A caveat of using these lead bars is that, they are prone to corrosion. Figure 3b shows two lead bars hold side by side to depict the effect of corrosion. With regular use, the tip of these lead bars even out with the body.

Participants and Survey

In this section, we discuss about the choice of our focus group and highlight important stories from our survey on their mathematics education.

Focus Group

We form our focus group involving the students from the aforementioned school. In this school, students used to get acquainted with academic mathematics in Class 4, and students of Class 5 are the seniors. Among several students from Class 4 and 5, we chose five students with diversified visual activities (Table 1). Two of them were from Class 4 and the rest were from Class 5. Here, we follow the classification provided by WHO [4] for classifying our participants' visual activity. We use the umbrella term 'visual impairment' to collectively term 'low vision' and 'blindness'.

Survey

We conducted a semi-structured interview for our participants. We asked them questions about how they solve regular arithmetic problems, their general opinion about existing system, and their recommendations for future tools. We also conducted a session where we asked them to do some addition, subtraction, multiplication, or division tasks using their regular tools.

How do you solve arithmetic problems?: We asked this question to our participants to understand existing method of solving arithmetic problems. Based on their answer, we present a simplified flow digram of the existing method to solve a arithmetic problem in Figure 4.

In the very first step, they perceive the problem description from the book or dictation by a teacher. They hardly use the mathematics book since following up long arithmetic problems and their narratives is tiresome and painful for them. Their classes are conducted through oral narratives and dictations.

Next, they understand the operands and the operation, put the operands in order on the math frame board using the lead bars, and calculate the answer (as shown in the Figure 6). Note that, they use the math frame board mainly for the proper placement and alignment of the operands and solution, which is not attainable through using the existing writing tool (Figure 2a). While doing arithmetic calculation, a child has to perceive the operands along with their relative positions and write down the solution step by step in paral-

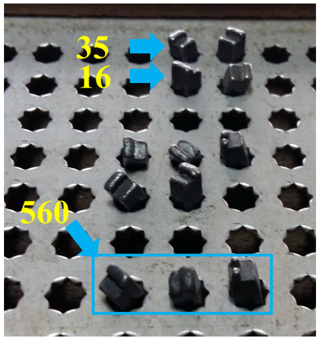


Figure 6: Correct answer of 35x16 multiplication task

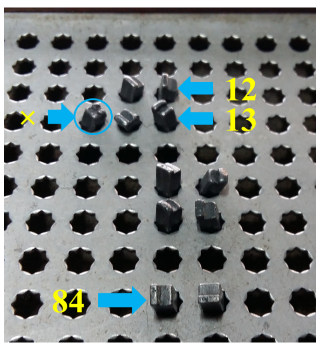


Figure 7: Incorrect answer of 12x13 multiplication task

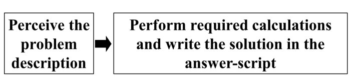


Figure 8: Flow digram of arithmetic problem solving using our proposed tool

Task	% of correct answers	Average total time in minutes (SD)
Addition	100	6.8 (0.45)
Subtraction	80	8.1 (0.8)
Multiplication	0	17 (1.2)

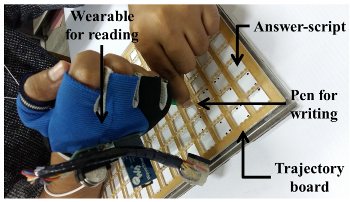
Table 2: Statistics while solving arithmetic problems using existing math tools

lel. However, in case of existing Braille writing system, one has to turn over the page to read out what (s)he has written. Even after reading, it is nearly impossible for a visually-impaired child to keep track of the operands or intermediate solution along with their relative positions from the other side of the paper, while writing the remaining part of the solution. Using the math frame board, a visually-impaired child can both perceive the operands along with their relative positions and put solution in the right place in parallel. Finally, they write the final answer in the answer-script using the writing tool (Figure 2a).

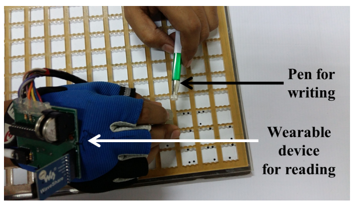
Problems with Existing Method: First, we asked them what types of problems they were familiar with among addition, subtraction, multiplication, and division. All of them replied that they were familiar with all operations, however, they are not comfortable with division. Therefore, we asked them to solve basic addition, subtraction, and multiplication problems using their existing tools. We dictated the problem statements as they feel comfortable with oral narratives. Upon perceiving the problem description, they implemented it in the math frame board, and then wrote it in the answer-script. In Table 2, we report the average total time taken by each participant to complete a given task. We also report the percentage of total time taken in math frame board operation and the percentage of correct answers we received from our participants.

We found the participants comfortable with simple addition and subtraction operations, although they took significantly higher time compared to a sighted person. Next, we asked them to multiply 16 with 35. Unfortunately, none of the participants were able to solve this task. We waited until ~ 20 minutes to pass by, in which they discussed among themselves, cross-checked each others' answers, and concluded on wrong answers. Figure 6 shows the correct answer after we intervened and corrected their spatial arrangement of lead bars. In another case, we asked P2 to multiply 13 with 12. He took 6.58 minutes to generate the answer in Figure 7. Note that he struggled with alignments in this case. When we said that the answer 84 was not correct, he attempted again and came up with 82 as the answer. The key take-away here is that, participants struggled while trying to align numbers along a column or a row.

We observed that, participants struggled with spatial reference when it comes to solving multiplication problems involving more than one digit. Besides, while they were touching the inserted lead bars to perceive the operands or intermediate solution in the middle of a calculation, the orientation of the lead bars got altered in most of the cases. Consequently, the digits enumerated by those lead bars got changed, which resulted in the wrong answers. Additionally, the lead bars with corroded tip exacerbated the situation. The participants could hardly perceive those tips, and hence the enumerated digits. These troubles in using the math frame board resulted in undesirably higher time to solve a basic arithmetic problem, and more than 80% of the total time was spent in using this board (as shown in the Figure 5). As a result, all the participants showed frustrations regarding existing method of learning and solving arithmetic problems.



(a) Writing



(b) Reading

Figure 9: Arithmetic problem solving and answer writing by using the proposed tool

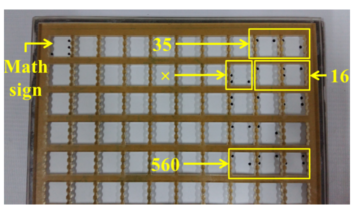


Figure 10: Complete solution of an arithmetic problem

Task	% of correct answers	Average total time in minutes (SD)
Addition	100	2.4 (0.2)
Subtraction	100	2.6 (0.35)
Multiplication	60	5.9 (0.6)

Table 3: Statistics while solving arithmetic problems using proposed tool

Proposed Solution and User Evaluation

Since our proposed solution for arithmetic learning leverages the system presented in our prior work, we refer the reader to our prior work [6] before going further. Figure 8 depicts a simplified flow digram of mathematical, particularly arithmetic, problem solving using our proposed solution. We draw the major contrast between the conventional means of solving arithmetic problems and our proposed solution through excluding the conventional math frame board, which engendered troubles during our aforementioned survey. In this case, the trajectory board, presented in our prior work, guides the proper alignment and placement of the operands. As a result, both the arithmetic calculation and solution writing in the answer-script can be done in parallel under the aegis of this trajectory board.

Figure 9 presents the reading and writing operations during the arithmetic problem solving by using our proposed tool. In this case, both Braille reading and writing operations are performed on the same side of a paper without turning it over. Figure 10 presents the complete solution of an arithmetic problem. A special Braille character, known as 'math sign', is written at the very first block of the answer-script. For the first time while reading with the wearable device, the tip of the wearable is placed in this block. Afterwards, the wearable device perceives any Braille character as a mathematical symbol.

To evaluate the performance and adaptability of our proposed solution, we conducted a brief user evaluation. For the preliminary user evaluation, we only chose participants P2 and P3, as they were familiar with the system presented in our prior work. We asked them to solve similar types of addition, subtraction, and multiplication problems using our proposed tool. Table 3 presents the average total time taken by each participant to solve a problem along with the percentage of correct answers. We observe the improvements in both metrics compared to the previous case. In this case, the total time required to solve a problem decreases by two-third of the previous timing.

Conclusion

Arithmetic workout in a paper context poses a challenge in the early stages of education for visually-impaired children. A low-cost and easy-to-use arithmetic learning tool considering the low-resource settings is yet to be proposed in the literature. In this study, we propose a Braille based arithmetic learning tool retaining all the aforementioned properties. Preliminary user evaluation involving visually-impaired children confirms its adaptability and potency.

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