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Virtual cubarithms – innovative assistive technology for teaching the blind and visually impaired students traditional columnar layout operations

Abstract. Blind students face significant barriers in their mathematical education. Despite currently available computer technologies they are not able to perform some simple operations, for instance, traditional columnar layout calculations, using a sheet of paper like their sighted peers. They have to use a traditional tool, namely, a cubarithm slate. In this paper a solution has been proposed to help blind students to learn and perform basic mathematical calculations with the help of a mobile device with touch screen. It is a Virtual Cubarithm application developed as a part of a larger research project called PlatMat. PlatMat is a special mobile platform supporting sighted teachers and their visually impaired students mathematical and physical education. Virtual cubarithm is a tool for learning traditional columnar layout calculations by visually impaired students. It is meant to replace traditional cubarithm slates, which are still in use.

Keywords: assistive technologies, the blind, mathematical formulas, virtual cubarithm, traditional columnar layout calculations.

1. Introduction

The teaching of mathematics, physics and chemistry to the visually impaired students causes some problems. The main difficulty results from the fact that mathematical, physical and chemistry formulas are spatial objects whose visual perception by this group of students is impossible or limited. The Braille notation of mathematical, physical and chemistry formulas is based on converting them into sequential representations, which naturally slows

down the students work. With the development of IT technologies, especially assistive ones, various aids are being offered to facilitate the study of the sciences. They include screen readers, sequential notations of the formulas entered from the computer keyboard or converters translating Braille mathematical symbols into MathML or LaTeX.

However, there are practically no IT solutions helping the blind to learn basic traditional columnar layout calculations which are mastered and used by every sighted student. Traditionally, for such calculations blind students used a slate and cubes with Braille figures, known as cubarithms, described in more detail later in the article. For students with low vision, who often struggle to maintain vertical orientation within the algorithm, no aids for the learning of this method of arithmetic calculations have been offered until recently. In 2014 the PlatMat project was started based on the research on the state of computerization of mathematics education in Poland [8] and information acquired through the authors' personal contacts with educational centres.

One of the innovative assistive technologies developed as part of the aforementioned project is virtual cubarithm. The technology takes the form of an independent application running under Windows 7.x or later, and a module that can be integrated with other PlatMat applications. The application takes advantage of the capabilities of the touch user interface and, the most importantly, is designed not only for blind students, but also for students with low vision, which is a novelty on a global scale. The latter are a group of users with different needs because of the different types of their vision impairment, therefore the solutions being offered must be very flexible and easily configurable for the users' needs. In this article we present the virtual cubarithm application, its functioning and how it can be adapted to the students individual needs.

2. Related work

Research conducted in science parks and commercial development of technologies and tools designed to increase the accessibility of mathematical resources in electronic form to blind users focus on two main directions. They are: increasing the accessibility of mathematical formulas and figures or enabling the blind to create and read them on their own. It is worth noting that few studies have brought up the need to increase the efficiency of math-related online communication with the blind. Below we briefly present such a research.

One of main trends is research on increasing the accessibility of mathematical formulas for editing and reading purposes. Presenting mathematical formulas to the blind faces many obstacles, mainly due to linear nature of both speech and Braille, which are their basic communication means. The use of linear notation systems for writing mathematical formulas, such as LaTeX or MathML, is inefficient due to lengthiness and problems with synthesized speech output. Although different Braille notations that are commonly used by blind students for explaining mathematical formulas are also linear, they are much more coherent than formats mentioned above. For this reason using braille to read and write math expressions is more practical. However there is no single standard of mathematical Braille notation, Gardner and Christensen [7] and Karshmer and Karshmer [4] propose a new, very efficient way of noting mathematical expressions for the blind. Wongkia, Naruedomkul and Cercone [11] propose i-Math, a screen reader-compatible system for automatic reading of documents containing formulas. Nazemi, Murray and Mohammadi [9] take a similar direction. Fuentes, Sepúlveda and Ferres [6] present the results of works on describing mathematical expressions using natural languages.

There are also research on formulas translation methods from commonly used notation systems into different national Braille variants. Such a solution has been proposed i.e. by Christensen, Keegan and Stevns [5]. They describe RoboBraille, a service for fully automatic conversion of text into several formats, including Braille. Archambault and Guyon [3] propose an open source library called UMCL (Universal Maths Conversion Library) with integrated converters for translating from commonly used notation systems (MathML, LaTeX) into different Braille notations. Few attempts other than the above-mentioned UMCL have been made to develop methods of converting mathematical formulas expressed in national Braille variants into commonly used notation systems, e.g. Alonso, Fuertes, Gonzales and Martinez [2].

There weren't do a lot of research which facilitate performing traditional columnar layout calculations by visually impaired students. According to the authors' current state of knowledge, there is no adequate solution to teach this skill to the blind using a computer. One of the solutions with the most similar functionality to that proposed in this paper may be the application described by Nancy Alajarmeh in the article: "E-Arithmetic: non-visual arithmetic manipulation for students with impaired vision" [1]. This is a simple web-based program which consists of 4 modules. Although it has a functionality to perform traditional columnar layout calculations by a blind student, in contrast to our proposed program it does not allow for customizing the appearance of the interface to the needs of visually impaired users with different vision problems. Also, it does not allow to determine the level of control operations performed by a student from the teacher, what our application offers.

3. Support for learning of traditional columnar layout calculations

The sighted students are carrying columnar layout calculation tasks by handwriting the appropriate configurations of numbers on a piece of paper (one below the other, one next to another, etc.). The blind students has to do this task in completely different way. Due to the linear nature of a Braille alphabet or speech description, which is used by them, performing this kind of calculations on a piece of the paper is not possible using a Braille machine. Therefore, the specially dedicated tool to help blind students with this kind of tasks was developed. It is called cubarithms. This is a special slate with square cups in which small plastic or metal cubes are placed. On each side of that cube, a Braille letter representing a digit is embossed. Depending on the position in the slate a cube can represent different digits e.g. letter b (braille dots 1 and 2) that corresponds to digit 2 can be rotated 90 degrees and then it is a letter c (braille dots 1 and 4) that represents digit 3. With this idea, each cube can be turned in the right way and put into slate so that mean the desired number from 0 to 9. A blind student may place cubes into the cups in the slate side by side and one above other and in this way he can set a different configurations of braille digits. Due to this, a blind student can perform traditional columnar layout calculation in a similar way as sighted one. The traditional cubarithms is presented in Figure 1.

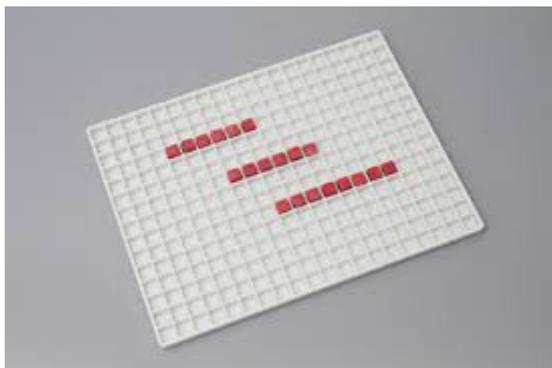


Figure 1. The traditional cubarithms

Let us note that the blind student who uses traditional cubarithms, usually works quite slowly. It is caused by the fact that in order to put a digit into the slate he must take the cubarithm cube on to his hand and rotate a cube in this way, that respective digit will be visible on top of the cube. Then he can insert the cube into proper hole in the slate. For this reason, performing the task of mastering techniques of traditional columnar layout calculation takes a long time. It seems that a good idea to significantly accelerate and make easier this process would be creation of a dedicated virtual cubarithm application. That application would replace the traditional cubarithms in manner that a cubarithm slate could be replaced by a virtual array similar to the one we meet in a calculation spreadsheet i.e. MS Excel. Then except placing one cube into the slate a student would involve only the location of the cursor in the appropriate cell and enter proper digit on the keypad.

4. Realization of virtual cubarithm

The virtual cubarithm application was created for the visually impaired students in order to replace traditional tool by smart software solution. Due to this program the student can operate touch gestures and keyboard for making one of the traditional columnar layout calculations such as multiplication on the screen of his tablet. He is able to navigate to each cell suspending a cube in traditional cubarithm slate and enter numbers using the keyboard in the same way as sighted student writes it on a piece of the paper. The view of virtual cubarithm user interface is presented in Figure 2.

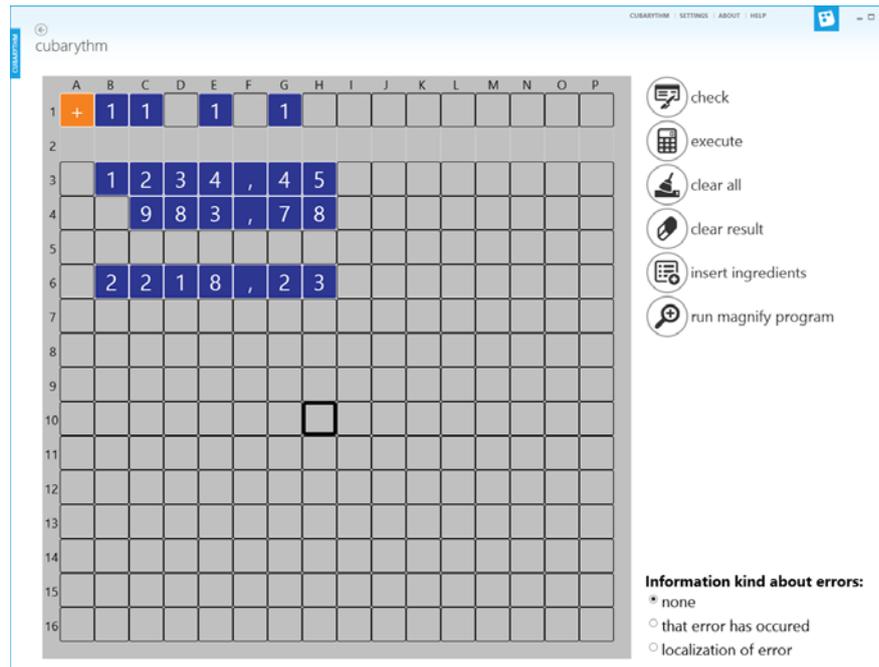


Figure 2. The view of virtual cubarithms screen

When the student navigates across the virtual cubarithm slate he can hear the position of each cell and a value that was entered to it previously. He can also enter digit using qwerty or braille keyboard into appropriate cell. The entered digit is announced for student by a speech synthesizer. After finishing the operation the student is able to check the correctness of his solution by pressing or tapping the appropriate button. Then the application will show him the place where mistake was made. Another option of our application is entering predefined configurations of calculation elements into cubarithm slate using specially designed wizard. For instance, when the student wants to make a multiplication task, he can enter first and second number to be multiplied in the wizard and accepts his choice. In this time an application will put entered numbers in appropriate places into the slate. It will give a possibility for a student to begin making an columnar layout multiplication task.

Therefore, all the traditional columnar layout calculation tasks performed by the student carried out with the help of virtual cubarithm application can be forwarded directly to the teacher's computer located in a remote location or inside. Due to this functionality the teacher is able to keep control of performance measures in writing by the student through a special virtual module which will display the student's activities on the teacher's screen. The communication between student and teacher can also go into opposite direction. A teacher can prepare a cubarithm task, put it into math document and send it to the student's application. A teacher can additionally block selected numbers in this task and establish the level of information about errors that will be available for student. In this way, he can make that student will be not able to get any information about his error in calculations or he will be informed only about this that he have made an error but without place where this error was made.

A cubarithm application has also some facilities for the users with low vision. The first of these is the possibility to run a magnifier program straight forward from the Cubarithm

application. Another advantage is the ability to choose the background color, as well as the color for the cell where number was entered. In this way the student can select appropriate contrast for his needs. The facilities explained above are presented in Figure 3.



Figure 3: Cubarithm facilities designed for users with low vision.

From technical point of view a virtual cubarithm application has been implemented in WPF (Windows Presentation Framework Foundation) and uses Modern UI templates. It can work as a module included in the blind student application, low vision student application and teacher application. It can work also as a separate application. A program can work under Windows 7 and newer systems. A virtual cubarithm has got also additional facilities for the blind such as writing numbers using one of available external braille keyboard.

5. User satisfaction study

The virtual cubarithm application was designed in cooperation with mathematics teachers from specialized institutions, and it was tested and reviewed while the work was in progress. The comments made by our consultants were taken into account during its development. However, to ascertain the opinions of a wider group of teachers from the whole of Poland, we conducted a survey on user satisfaction among the users of this innovative IT study aid. The study concerned all the PlatMat applications, and the respondents were mathematics teachers from 5 special schools for visually impaired children, as well as two schools with integration classes, who had taken part in workshops on the use of the PlatMat applications. The survey examining user satisfaction with virtual cubarithm was completed by 18 respondents out of

the total of 22 people taking part in the study. The survey consisted of three extended questions; the percentage of positive answers is given after each one.

Question 1. Improved assistance for the student in mastering the rules of performing calculations - by means of:

- a) Making it easier to enter the numbers correctly within the algorithm (the digits of every number placed correctly above or below each other)

100 % YES

- b) Locating errors in calculations more quickly using the CHECK function

100 % YES

- c) Making it easier to enter numbers into the cubarithm slate and making it possible to perform calculations using different interfaces: QWERTY keyboard, Braille keyboard, touch gestures.

100 % YES

- d) Adapting the application interface to the needs of students with low vision (setting the colours of the background and cells, access to functions by means of keyboard shortcuts)

100 % YES

- e) Attractive graphic form and replacing the traditional cubarithms slate and cubes with their electronic version

100 % YES

Question 2. Increasing the student's independence in performing under the traditional columnar layout calculations at home - by means of:

- a) Allowing the student to create problems on his own for purpose of self-education or preparation, for instance before a test

100 % YES

- b) Locating errors in calculations more easily by means of the CHECK function

100 % YES

- c) Being able to learn the correct notation or verify the notational correctness of one's calculations by means of the PERFORM function

100 % YES

Question 3. Making it easier and quicker for the teacher to teach visually impaired students to perform columnar layout calculations by means of

- a) Quickly creating mathematical problems on the cubarithm, with the option to review and correct them as part of digitized educational resources (problems, work sheets), which are uniform, regardless of the type of vision impairment of the student who will use them

17 YES, 1 - no opinion

- b) Making it easier for the teacher - once the student's work has been submitted - to check the correctness of arithmetical calculations performed by means of algorithms

17 YES, 1 - no opinion

- c) Using mathematical problems of the cubarithm's type in various contexts (homework, test, exercises) by choosing the appropriate settings of the error notification function

17 YES, 1 - no opinion

The numerical results of this study, as well as opinions offered as additional comments in the surveys, indicated that the potential users expressed the greatest satisfaction with the cubarithm application. These results were one of the reasons for presenting the application in a separate article. The study itself will be presented in full in a text now being prepared for publication in a foreign periodical.

6. Conclusions

The study in question, conducted at the close of the PlatMat project and statements made by the participants of the conference devoted to PlatMat (October 28th 2015 at the Institute of Mathematical Machines in Warsaw) indicated, on one hand, the need to continue developing the PlatMat technology in the suggested directions (such as the technology for mathematics tests for students with visual impairment, or technology supporting group work), while on the other hand - the need to develop a prototype of the PlatMat platform and test it in real conditions of educational centers by teachers and students. The creation of this prototype, ready for implementation, testing it for many aspects and winning the recommendation of the educational community is the goal of the research project: „OPTY: A study of the effectiveness of the computerization of mathematical education of students with visual impairment using optimized PlatMat tools”, currently being carried out at the Institute of Mathematical Machines.

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