Multimodal Interface for Working with Algebra: Interaction between the Sighted and the Non Sighted

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Abstract. In an integrated school environment for Mathematics learning, effective communication and collaboration between sighted and non sighted students and teachers is a crucial aspect. Common activities in the classroom as doing dictations, exercises and exams, become cumbersome without an adequate support. We have developed a prototype interface to support these activities using visual, speech and braille output modalities. User testing with students showed that the interface facilitated writing, manipulation and communication.

Keywords: visual disability, accessibility, mathematics, HCI

1 Introduction

At present, non sighted students still struggle to follow Mathematics courses, and very few of them pursuit higher level Mathematics related studies. Students need to understand concepts, take notes, make questions and submit homework amongst other activities. While they can manage to use braille to perform most of these activities, they need the help of an intermediary to communicate with their sighted peers and teachers. At times, they also face the problem of following verbal descriptions based in spatial aspects of the concepts being explained. Taking into account the needs of sighted and non sighted students and teachers, we developed a prototype interface where sighted and non sighted students can produce and manipulate mathematical contents, and visualize them in a synchronised way. A set of features that aim to facilitate the resolution of basic algebra equations is included in this interface. The possibility to use such an interface could bring some advances working in an integrated environment.

2 State of the art

Regarding the access and work with mathematics with a sighted-non sighted collaborative orientation, there exist software to visually represent mathematical contents including speech output, such as the Math Genie [1], InftyReader [2], braille output such as the MAWEN prototypes [3], or both, such as LAMBDA [4]. LAMBDA uses a linear visualisation of expressions and allows copying and pasting terms as an aid for solving. The MAWEN prototypes includes assistants to support manipulation and simplification [5], though the results showed that they needed improvement. Other research projects concern the analysis of the audio output using prosody, earcons, spearcons and lexical cues [6], and presentation modalities based in complexity [7, 8], amongst others. Aiming to support more advanced studies in mathematics, other projects use LaTeX as input, and either braille or audio as output. LABRADOOR [9], converts LaTeX into the Marburg braille code; the LaTeX-access project [10] produces mathematical braille according to the Nemeth code, and the project PSLM (Programme Spécialisé de Lecture Mathématique à l'Usage des Non-Voyants) takes a LaTeX input to produce an audio output in French. These projects have facilitated to some extent the access to mathematics for the blind, though most of them, with the exception of LAMBDA and InftyReader, are research projects which are not available to end users as AT products.

There exist as well another type of software with advanced capabilities as symbolic calculators aimed for the general user, such as Sage, Axiom and Mathematica. However, the use of this type of software is not recommended for educational purposes since it performs automatic transformations which can affect the development of the student's algebraic symbolism [11, 12]. On the other hand, most of them are based in graphical interfaces which are, most of the time, not accessible to screen readers.

3 The interface

We have developed an interface with the aim to facilitate the edition, comprehension and resolution of algebraic equations using visual, speech and braille output modalities. The development of the interface followed a User Centered Design approach, after which design is based upon an understanding of users and the tasks to be undertaken, and potential users are involved in the development.

Firstly we analysed the actions of sighted and non sighted students while solving linear equations, as well as those of mathematics teachers while explaining the resolution. Teachers were also interviewed regarding the didactical aspects to be considered. The results of the analysis are reported in [13].

The development followed an iterative process which began with the implementation of edition and navigation according to the needs detected in our first analysis. A first prototype was reviewed by users and modified according to their suggestions. A second round of functions were implemented in the latest version, whose evaluation we present in this article.

The latest version of the interface has the following features:

- Edition of basic algebra equations, involving exponents, fractions and square roots, using the computer keyboard and the braille keyboard. We use delimiters to indicate the beginning and the end of fractions and square roots.

Writing delimiters with the computer keyboard implies the use of shortcut keys, or menus.
- Possibility to visually display expressions in a bidimensional and linear way.
- Synchronised visual, audio and braille display.
- Folding and unfolding of sub expressions.
- Display and navigation by semantic blocks according the levels of the expression tree.
- Search of parts of the expression, search of common terms.
- Marking of terms and shortcuts to "jump" between them.
- Possibility to keep the cursor in the last visited position of each line.
- Possibility to read and copy marked terms independently of the position of the cursor.
- Possibility to save contents on file in MathML format.

The interface was developed in the Mozilla Platform, using XUL for the graphical interface, Python for the back-end and MathML for the visual representation. The MathML expression tree is transformed dynamically as elements are typed. Marking and folding of terms are indicated internally by the use of additional boolean attributes. The synchronisation to braille is achieved through a conversion table; a string representing the audio output is built and then passed on to the screen reader. NVDA is used to control the audio and braille output on Windows.

We used a Model-ViewController (MVC) architecture to facilitate implementation and modification of the interface components (see Figure 1).

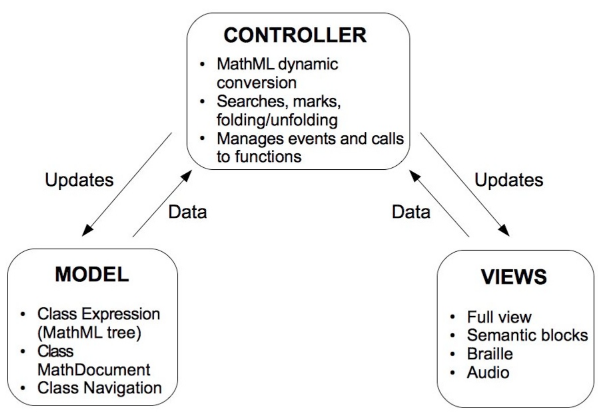

Fig. 1. Model-View-Controller Architecture.

The interface and its views is shown in Figure 2. An example of expression is written in the bidimensional and linear modalities in line 1 and 2 respectively. The braille output is the same for both. The block view and the audio string reflect the active term.

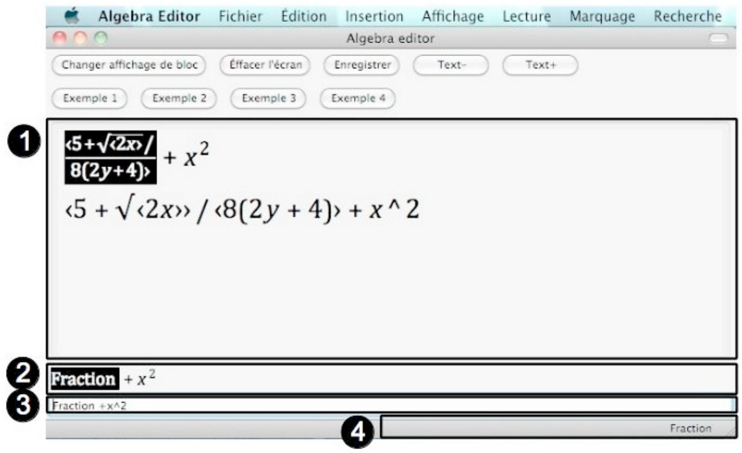

Fig. 2. Bidimensional and linear writing of an expression. Views : 1) Full expression, 2) Semantic blocks, 3) ASCII Braille, 4) Audio string.

4 User testing

The purpose of the evaluation was to observe the possible difficulties while typing with the computer keyboard or the braille display, the ease of verification of the written terms by audio or/and braille, the recognition and recovery from typing errors, the memorisation of shortcuts, the difficulties in understanding expressions, the efficacy of communication teacher-student and the possibility to execute the desired strategy for solving.

The participants were :

- 4 mathematics teachers : 3 with normal vision, 1 partially sighted.
- 6 students: 2 non sighted students from high school, and 4 from junior high school, of which 3 are non sighted and 1 is partially sighted.

The test consisted of four parts:

1. **Writing/reading expressions.** Participants (teachers and students) wrote expressions using either the keyboard or the braille display, following a practical demonstration on how to write exponents, fractions and square roots.

$$3x^2 - 6 = 3(x^2 - 2) \qquad \frac{2x}{x+2} = \frac{4}{x-10} \qquad \sqrt{x+4}$$

2. **Comprehension.** The student is given three nested fractions of increasing complexity, and is left to analyse each of them using the audio output. We wanted to observe the efficacy of the audio output, as well as the participant's use of the navigation by blocks. The features were demonstrated to each participant, but its use was not mandatory. Following the analysis of each fraction, the student was asked to reproduce it verbally.

$$\frac{a+\frac{b}{c}}{d+e} \qquad \frac{\frac{a+b}{c+d}}{x-y} \qquad \frac{\frac{x+1}{8+y}}{\frac{x-1}{9+z}}$$

3. **Communication.** The teacher dictates to the student an expression involving a fraction, a square root and parenthesis. The teacher verifies the output and proposes a correction if necessary.

$$\frac{5+\sqrt{2x}}{8(2y+4)}$$

4. **Solving.** The student is given 3 equations to solve, involving simplification, distribution, clearing of fractions and parentheses. This part was done exclusively with audio output.

$$7-\frac{x+3}{x}=5 \tag{1}$$

$$x+2(x+2(x+2))=x+2 \tag{2}$$

$$(3a^2+2a+7)(a+5a-4) \tag{3}$$

The tests were executed on Windows XP and 7, with a Papenmeier Braillex Trio. The partially sighted teacher used a computer with Mac OS X Mountain Lion and the system zoom. The tests were performed in three different high schools in France.

5 Results and discussion

Writing. Students have different levels of knowledge on the use of the computer, the braille display and the mathematical braille code; therefore they had different abilities and preferences for the input/output modalities. Typing exponents, fractions and square roots did not present important difficulties, though the users require to get used to using shortcuts in order to write bidimensional structures using the keyboard. They agreed that the audio output is comprehensive, but it can be very tiresome if used alone. Participants got used to identify and correct errors in a short time. The braille input, whose interactions were more limited in implementation than those of the computer keyboard, allowed participants writing fractions, roots and exponents.

Comprehension. Teachers expressed that understanding a mathematical expression involves recognising the symbols, understanding the organization of the expression, and knowing how to start the solving process. In the activity of listening and reproducing the structure of the nested fractions, students were able to reproduce correctly the structure of all three. In general students preferred to listen to the full fraction, even if it meant to listen to it 2 or more times.

We observed that they were more susceptible to use the navigation by blocks as fractions became more complicated. On the other hand, students expressed that in cases like this is when one can really appreciate the braille representation.

Communication. The direct communication between student and teacher was very effective in all cases. The teacher dictated the expression in the way he is used to; some teachers consider that dictation must be particular for blind students, for example : "now I'm going to tell you the terms in the numerator", while others would dictate the same way they would to sighted students. The student wrote the expression and the teacher validated the writing or made corrections. Since the students had already written fractions and roots, they did not make significant errors. The immediate visualization of the student input during dictation was greatly appreciated by teachers.

Solving. Not all participants were able to do this part of the evaluation since they did not have the required knowledge of algebra. Only the 2 students from high school were able to do the solving exercises. Junior high school students participated in the edition, reading and dictation exercises, but their teachers mentioned that the students had not learned operations with fractions, and that the exercises were too complex for them. Only one of the junior high school solved a linear expression proposed by her teacher; this student was not familiar with the computer keyboard, so she used the braille device.

The two students who were able to perform this part expressed some kind of frustration when presented with a simplification of multiple terms and the distribution of 2 factors of 3 terms each, but they did not express discouragement when realising the complexity of a double nested expression, or the expression involving the clearing of a fraction. Both students solved correctly the expression with nested parentheses. Figure 3 shows the solution of one of the students, who identified an initial simplification and then carried on with distribution.

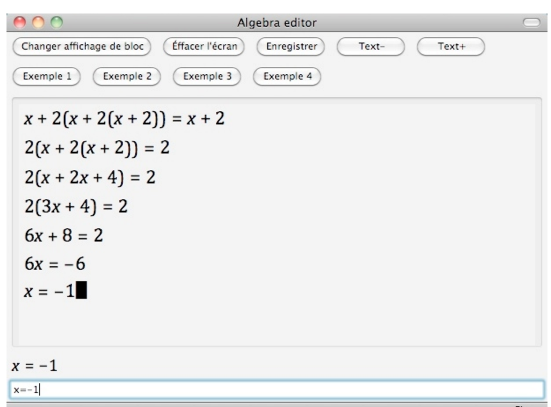

Fig. 3. Student's solution to equation 2.

Students used the functions to fold and unfold sub expressions while exploring exercise 3:

$$
\begin{aligned}
&\boxed{PRODUCT}\\
\rightsquigarrow\ &\boxed{FACTOR}\,FACTOR\\
\rightsquigarrow\ &(3a^2+2a+7)\boxed{FACTOR}\\
\rightsquigarrow\ &(3a^2+2a+7)(a+5a-4)
\end{aligned}
$$

One of the students used the search for common terms after the simplification of quadratic terms, in order to make sure he had considered them all. We observed that the possibility to go back to the last visited position of each line was very useful, especially during distributions, since it allowed students to follow up the order of multiplications.

For most of the activities, students tried to replicate on the interface their usual work in text editors or in the braille display. They did not use the navigation by blocks very often, and they did not use the function for marking terms. This could be due to the recent introduction of this functions in their usual work environment and the mental load of having presented all the features and shortcuts at the same time. Further exposure to such features during real exercises could allow us to observe whether they support resolution or not.

While the interface provides basic braille input and output, the braille implementation for interaction must be improved so that it also allows reverse pointing with its correspondent visual highlight. On the other hand, it was observed the need to personalize shortcut keys and levels of verbosity of speech according to the users' preference.

6 Conclusion

We have presented a prototype of interface which implements edition and navigation, and includes a set of features to help users solving basic algebra equations, using synchronised views in different modalities. The results of the tests with students and teachers were favourable in general.

Communication is probably the most critical aspect for the integration of a non sighted student in a mainstream environment. This communication does not only involves visualizing what the other is doing, but also being able to do it while using their preferred method for writing and reading contents. Users have different backgrounds and preferences; offering multiple modalities on an interface it is also part of the consideration for user diversity. We performed a second type of tests in a cognitive walkthrough modality with Mathematics teachers with experience working with non sighted students, in order to verify the pertinence of the features regarding didactical aspects. While the results of the tests are encouraging for this level of education, we need to open up the possibilities for students in more advanced levels. Higher studies of Mathematics currently demand the knowledge of LaTeX for working with complex documents; however, the verbosity of LaTeX makes it hard to use with a screen reader and a braille display. It would be interesting to analyse the implementation of the dynamic visualisation, synchronisation and access features proposed in our work, in order to create and maintain LaTeX documents in a more straightforward way.

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