Supporting braille readers in reading and comprehending mathematical expressions and equations

Annemiek van Leendert[1], Michiel Doorman[2], Paul Drijvers[2], Johan Pel[3] and Johannes van der Steen[3]

[1] Royal Visio, the Netherlands; annemiekvanleendert@visio.org

[2] Utrecht University, the Netherlands; m.doorman@uu.nl and p.drijvers@uu.nl

[3] Erasmus University Medical Center; the Netherlands; j.pel@erasmusmc.nl and j.vandersteen@erasmusmc.nl

Braille readers create an overview of an expression by reading one braille character after another or listening to a voice saying the expression or equation aloud. The specific skills and knowledge that mathematics teachers need to assist this complicated process are often lacking. The purpose of this study was to investigate the effect of an intervention consisting of a course focused on braille display support in combination with Text-To-Speech synthesizer for mathematics teachers on the mathematical performances of braille readers. A quasi-experimental approach was taken to answer this question. Five teachers of an experimental group received the intervention whereas the teacher of the control group did not. Both the experimental group, consisting of 10 braille readers, and the control group, consisting of five braille readers, took a pre- and post-test. The results indicated that there was a very small positive effect of the intervention.

Keywords: Braille display, braille reader, algebra, speech synthesizer, TPACK model.

Introduction

Reading and comprehending mathematical expression and equations has always been difficult for students who use braille or braille in combination with speech synthesis as their primary reading medium (hereafter braille readers). Mathematics teachers need to have specific skills and knowledge to assist this complicated process. Braille readers read and comprehend mathematical expressions and equations by touching or hearing in a sequential pattern (Millar, 1994, 1997). They need to build an overview by reading one braille character after another or listening to a voice saying the expression or equation aloud. Expressions and equations have to be represented in a linear notation because braille and speech are both linear output modalities (Stöger & Miesenberger, 2015). Hence, braille readers have a small perceptual view and have to read expressions in a linear notation. This means that they can’t benefit from the layout of an expression that helps the sighted student to understand the structure of an expression at a glance (Karshmer & Bledsoe, 2002).

In many countries, braille readers in secondary and higher education use a laptop in mathematics class. Screen Reader software sends the mathematical text on the screen to a refreshable braille display, which is connected to the keyboard of the laptop, or to a Text-To-Speech (TTS) synthesizer. Consider, for example, the next expression:

$$\frac{2x^2+1}{3} \qquad (1)$$

In this representation, the expression can’t be sent to the braille display or TTS synthesizer. It must first be converted to a linear representation (hereinafter pre-braille notation), e.g. (2x^2 + 1)/3.

The notation on the braille display is to a certain degree static. This allows for at least a limited spatial overview (Archambault, Stöger, Batusic, Fahrengruber, & Miesenberger, 2007). On the other hand, every character on the braille display has to be read individually and sequentially which makes braille reading exhaustive rather than selective (Hughes, 2011; Hughes, McClelland, & Henare, 2014). That makes it rather difficult to get an overview over an expression or equation (Van Leendert, Doorman, Drijvers, Pel, & van der Steen, 2019). Moreover, braille characters have a low redundancy, which means that the characters are hard to distinguish from each other (Tobin & Hill, 2015). This can lead to errors in decoding the braille characters into correct elements of the expression or equation.

In addition to the braille display, the TTS synthesizer is a useful screen reader device for reading mathematical expressions and equations. The Screen Reader that controls the speech and that we used in this study is JAWS, which stands for Job Access With Speech. An advantage of speech over braille is the pace of reading because spoken language can be much quicker comprehended then braille characters. Mathematical expressions and equations can be spelled or read aloud. When an expression is spelled, each element in the expression is approached separately. When an expression is read, a speech dictionary determines the spoken text. This dictionary can be extended with a mathematics vocabulary (also influencing how non-mathematical text is read) and can be further extended with mathematical symbols on so-called verbosity levels. The way in which an expression is spoken aloud depends on the content of the dictionary and the verbosity levels and on the verbosity level at which the braille reader reads. For example, “2(x^2 + 4)” can result in “two x squared plus four” when using a low verbosity level and in “two open bracket x squared plus four closed bracket” when using a high verbosity level. In this case, the meaning is lost when the braille reader uses a low verbosity level. In general, braille readers (should) use a low verbosity level for reading non-mathematical text and a high verbosity level for mathematical text. By default, the settings are not adjusted to mathematical text. In that case, choosing a high verbosity level doesn’t help.

In summary, the Screen Reader’s software can be adjusted in such a way that (almost) all expressions are spelled and read in mathematical vocabulary. This supports the braille reader in learning the mathematical vocabulary, which is vital for the development of mathematical skills (Riccomini, Smith, Hughes, & Fries, 2015). Moreover, this vocabulary corresponds to the vocabulary used by the mathematics teacher in the classroom. This is particularly useful for braille readers in inclusive classrooms, because individual support is not always available.

Both assistive devices, the braille display as well as the TTS synthesizer, have their strengths and weaknesses. Ideally, using both devices one combines their individual strengths to overcome the weakness of each of the two methods (Bernsen, 2008). For example, uncertainties in braille can be verified or checked by spelling aloud.

The previous sections demonstrate that reading and comprehending mathematical expressions and equations while using the braille display or the TTS synthesizer is not easy. Teachers often don’t know how to guide this complicated process. To map out the qualifications of mathematics teachers, the TPACK model can be used. TPACK includes knowledge of technology (TK), pedagogy (PK) and content (CK), as well as insight into the complex interaction between these knowledge components (Mishra & Koehler, 2006). The idea behind TPACK is that the pedagogical use of (assistive) technology devices is strongly influenced by the content domains on which these devices are situated (Graham, Burgoyne, Cantrell, Smith, St Clair, & Harris, 2009). For example, the teacher knowledge required to effectively integrate technology in a mathematics classroom may be very different from that required for a language classroom.

This study aims at improving the integration of the braille display and the TTS synthesizer in the mathematics classroom. We addressed the following research question:

What is the effect of improving the knowledge of braille display and Text-To-Speech synthesizer support of mathematics teachers on braille reader’s achievement in mathematics?

We expected that braille readers will better perform in mathematics because the adjusted settings of the Screen Reader software are more appropriate for reading mathematical text and the mathematics teachers have the knowledge to teach the braille readers how to use the braille display and the TTS synthesizer in mathematics lessons.

Methods

Design

In this study, the braille readers’ mathematics teachers took part in a professional development (PD) course on integrating the braille display and the TTS synthesizer into mathematics lessons. The first part of the course was aimed at assisting each teacher in adjusting the settings of the Screen Reader software. As a result, the braille readers were able to listen to how expressions and equations were spelled and read aloud in mathematical vocabulary. The second part of the course was aimed at improving the knowledge to teach the braille readers how to use the braille display and the TTS synthesizer in mathematics lessons. In order to answer the proposed research question, a quasi-experimental approach was taken, using a pre- and post-test. The experimental group consisted of 10 braille readers whose teachers took part in the PD course. The control group consisted of five braille readers whose teacher did not participate in this course.

Context and participants

In the Netherlands, more than 50% of all braille readers in secondary education go to special schools for students with a visual impairment. Organization A and B provide education for these students. The first author was affiliated with organization A. Therefore, five mathematics teachers from two different schools of organization A participated in the PD course, while the teacher who worked at the school of organization B did not. None of the teachers ever received any training in teaching mathematics to braille readers. The mathematics teachers who worked at organization A were qualified teachers, but they were not, with the exception of one, qualified to teach mathematics. In contrast, the mathematics teacher who worked at organization B was a qualified mathematics teacher. The braille readers of organization A were assigned to the experimental group and the braille readers of organization B were assigned to the control group. This resulted in an experimental group of 10 and a control group of five braille readers. The three schools were very similar in terms of demographic characteristics of students and the degree of educational performance. The braille readers were all in seventh to twelfth grade in secondary education. They differed in their mathematical skills and in their ability to use the braille display and the TTS synthesizer.

Intervention: a professional development course

Part of the intervention consisted of the adjustments of the settings of the Screen Reader software. The control group worked with the “old” settings, and (often) used one verbosity level when reading. As a result, too few symbols and punctuation marks were read aloud in mathematical text, or too many punctuation marks were read aloud in non-mathematical text. Moreover, (almost) no mathematical vocabulary was used. For the experimental group, the verbosity settings of the Screen Reader were adjusted. The speech dictionary was extended with a mathematical vocabulary and all punctuation marks and symbols, used in pre-braille notation, could be spelled aloud in mathematical vocabulary. The braille readers could choose a verbosity level with which they could read the whole expression aloud in mathematical vocabulary, without missing elements.

The face-to-face PD course consisted of four sessions of three hours each, which lasted over a period of four months. The design of the course was based on TPACK. Much attention has been paid on how to integrate the braille display and the TTS synthesizer into the mathematics lessons. For the first homework task, the mathematics teachers were asked to support a braille reader in obtaining an overview over an expression or equation. For the second homework task, they were asked to write down their experiences with the adjustments of the Screen Reader software and to discuss this with their braille readers. For the third task, they were asked to do an activity to provoke collaborative work and mathematical communication between students.

Pre- and post-test

We decided that we could use identical pre- and post-tests because the time interval was more than four months. The braille readers were asked to answer the two tasks orally, because that would save time and be less tiring for them.

The tasks were not too complex but required careful reading skills due to the use of various operations and brackets. In the first task, “synthetic speech comprehension”, the braille readers had to select information from expressions or equations that were spoken aloud. The items could be spoken aloud several times at the request of the braille reader. The items were:

a) 1/7 + 7 - 2/5 + 8 = .. What are the fractions in this expression?
b) 4 - (5 + -(6 + 3)) = .. Where do you start calculating?
c) 4 * (.. - 5) = 8 Solve this equation.

In the second task, “mathematical braille reading skills”, the braille readers were asked to read the mathematical text on the braille display and verbalize this text in mathematical vocabulary. With item b we expected to be able to investigate whether they were supported by context. The items were:

a) y = 2 1/2 * 3
b) The volume is 12 m^3
c) y = sqrt(2/(x + 3)^2)

(2 1/2 is a mixed number, a combination of a whole number and a proper fraction). Before the start of the pre- and post-tests, the braille readers were interviewed about their visual impairment, their assistive devices and the support they receive in mathematics lessons. This information helped to interpret the results of the tests.

Procedure

The research followed this order: pre-interview, pretest, intervention, post-interview, posttest, all within a maximum of five months. The interviews and the pre- and post-tests took place at the schools of the braille readers. All sessions, consisting of an interview and a pre- or post-test, were scheduled for 25 minutes but sometimes lasted longer due to technological problems with the braille readers' laptops. Within two weeks of completing the pretests, the Screen Reader software of the experimental group was adjusted and the mathematics teachers' development course started. Within a month after the end of the course, the braille readers did the posttest. The control group received the same interviews and pre- and post-tests in the same period but without intervention.

Data collection and analysis

For investigating the research question data was collected during the pre- and post-test through audio and video recordings. For "synthetic speech comprehension", data were collected on whether the braille readers gave a correct answer and on how much time they needed to give this answer. For each group, the average time was calculated. For "mathematical braille reading skills", data were collected on whether the braille readers could verbalize the expression, how much time they needed to give a correct answer and on the kind of errors they made. For each group, the average time was calculated.

Results

The results in Table 1 show that for synthetic speech comprehension, the pretest percentage of correct answers was 57% for the experimental and 47% for the control group. For the posttest, the percentage of correct answers was (again) 57% for the experimental and 80% for the control group. The experimental group needed in the pretest, on average 46.1 seconds (SD = 27.0) and in the posttest, on average, 34.1 seconds (SD = 16.0) to give the correct answers. The control group needed in the pretest, on average, 45.4 seconds (SD = 25.1) and in the posttest, on average, 32.4 seconds (SD = 14.3) to give the correct answers. For both groups, the standard deviations were high.

For mathematical braille reading skills, the pretest percentage of correct answers was 20% for the experimental and 53% for the control group. In the posttest, the percentage of correct answers was 37% for the experimental and 60% for the control group. The experimental group needed in the pretest, on average, 18.2 seconds (SD = 26.8) and in the posttest, on average, 15.3 seconds (SD = 8.7) to give the correct answers. The control group needed in the pretest, on average, 9.0 seconds (SD = 3.1) and, in the posttest, on average 9.8 seconds (SD = 8.4) to give the correct answers. Also for this task, the standard deviations were high. The errors were categorized. E(d) is an error made due to difficulties with decoding the braille characters. This could be ascribed to difficulties with recognizing the location of the raised dots or to difficulties with decoding the braille characters into correct elements of a mathematical expression (e.g., "x" "^" "2"). E(v) is an error due to difficulties in recognizing and verbalizing the whole expression (e.g. "x squared") and E(b) is an error due to malfunctioning of one of the technology devices. For both groups and for all tests, almost all errors were decoding errors. For both groups, most decoding errors occurred at decoding symmetric or translated characters (e.g. ⠏⠹ and ⠋⠖) and mixing up six dot braille with eight dot braille. The E(b) error occurred only, two times, in the pretest of the experimental group.

Table 1: Results from pretest and posttest for synthetic speech comprehension and mathematical braille reading skills

		Pretest		Posttest	
Condition	Number of students	Percentage of correct answers	Average time on correct answers (s.)	Percentage of correct answers	Average time on correct answers (s.)
Synthetic speech comprehension	E (*10*)	57%	46.1 (SD = 27.0)	57%	34.1 (SD = 16.0)
	C (*5*)	47%	45.4 (SD = 25.1)	80%	32.4 (SD = 14.3)
Mathematical braille reading skills	E (*10*)	20%	18.2 (SD = 26.8)	37%	15.3 (SD = 8.7)
	C (*5*)	53%	9.0 (SD = 3.1)	60%	9.8 (SD = 8.4)

E denotes experimental and C control group

Finally, we illustrate the decoding practices of two braille readers of the experimental group reading “The volume is 12 m^3” on the braille display (see Table 2). In this example, I. tried to read 12 m^3 as one number “2393”. He did not recognize the “^” character in braille and stopped. F. also started with reading 12 m as one number, but corrected the error. Both braille readers mixed up “m” with “3”. and spent a lot of time reading "12 m^3" compared to reading "The volume is".

Table 2: Results of two individual braille readers on mathematical braille reading skills

Braille reader I. (pretest)		Braille reader F. (posttest)	
Time (s)	Utterances	Time (s)	Utterances
00– 04	The volume is	00 – 01	The volume is
04 – 17	Two thousand three hundred ninety-three Wait two thousand What should this be?	01 – 19	Eh hundred three and twenty No no twelve I think this is cubic 12 cubic meters
17 – 22	The volume is		
22 – 40	one, two three no wait a two m s three I do not know if that is an s. It looks a bit strange ... {stop}		

Conclusions and discussion

This study aims at improving the integration of the braille display and the TTS synthesizer in the mathematics classroom. For “synthetic speech comprehension”, the percentage of correct answers for the experimental group (57%) did not change during the intervention. This means that, for this the task, there was no evidence that the intervention was successful. For the control group, this percentage was 47% in the pretest and 80% in the posttest. It is remarkable that this group achieved much better on the posttest. For “mathematical braille reading skills”, the experimental group improved more than the control group. It is remarkable that the pretest percentage of correct answers of the experimental group (20%) was much lower than that of the control group (53%). In the posttest, the percentage was 37% for the experimental and 60% for the control group. For both groups, most errors were errors in decoding the braille characters showing that braille readers already stumble in the first phase of the solving process. Table 2 shows that braille reader I. and F. needed more time and made more errors when reading mathematical text (“12 m^3”) compared to reading non-mathematical text (“The volume is”). Both braille readers mixed the symmetric characters “3” and “m”, which is a common mistake (Tobin & Hill, 2015). In summary, the results of the tasks on mathematical braille reading show a very small positive effect of the intervention. We expected a greater effect. Finally, the high values for standard deviation, in all tests, showed that the individual differences were large.

This study had some limitations. A first limitation was the small number of braille readers that participated in this study, especially the number of participants in the control group. A second limitation was the limited information we had of the braille readers about the frequency that they used the adjustments of the Screen Reader software in the period between the two tests. From a teacher’s point of view, we don’t know, exactly, if and how they changed their daily practice. This feedback was asked during the second interview, yet the braille readers found it difficult to reflect on this.

Moreover, there were differences between the experimental and control group that may have affected the results. Firstly, the braille readers of the control group were obliged to use the braille display, whether or not in combination with the TTS synthesizer, during their mathematics lessons. This was not obligated for the braille readers of the experimental group. Secondly, the mathematics teacher of the braille readers of the control group was a qualified mathematics teacher. This was not the case for the mathematics teachers, with the exception of one, of the experimental group.

We did not anticipate that braille readers would make so many decoding errors while reading mathematical text. Overall, the control group performed better on both tasks than the experimental group. This may be due to the strict rules for the use of the braille display and the differences in background of the mathematics teachers. This could be examined in more detail in future studies.

Overall, this study adds to the small number of studies into ways to support braille readers in mathematics (e.g. Figueiras & Arcavi, 2014). Findings from this type of research should enable teachers to better support braille readers in doing mathematics.

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