

# A Braille Writing Tutor to Combat Illiteracy in Developing Communities

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## Abstract

Less than 3% of the 145 million blind people living in developing countries are literate. This low literacy rate is in part due to the lack of trained teachers and the challenges associated with learning to write Braille on a traditional slate and stylus. These challenges include writing from right to left, writing mirrored images of letters, and receiving significantly delayed feedback. Extensive conversations with the Mathru School for the Blind in Bangalore, India, revealed the need for a robust, low-power, low-cost Braille writing tutor. In this paper, we present the design and deployment of our writing tutor system that uses a novel input device to capture students activity on a slate and stylus and uses a range of scaffolding techniques and Artificial Intelligence to teach writing skills to both beginner and the advanced students. The paper also reports lessons learned in the implementation of this project and from a six-week pilot study at the Mathru school and outlines future directions for improvement.

## 1 Introduction

More than 90% of the world's 161 million blind and visually impaired people live in developing communities [World Health Organization, 2004]. Despite the importance of literacy to employment, social well-being, and health, the literacy rate of this population is estimated at below 3% [Helander, 1998].

Braille, the primary method of reading and writing for the blind, is a tactile system in which embossed dots representing letters, symbols, and numbers can be read with the fingers. A Braille letter is formed by embossing some subset of six dots arranged in a  $3 \times 2$  cell. Figure 1 shows schematics of a Braille cell and a photograph of a page of Braille. For the blind, literacy in Braille is often the key to independence in home and at work [Schroeder, 1989]. It is said that the system has "liberated a whole class of people from a condition of illiteracy and dependency and has given them the means for self-fulfillment and enrichment" [Nemeth, 1998].

Despite the advantages that Braille literacy imparts, there are a number of barriers to learning Braille in developing

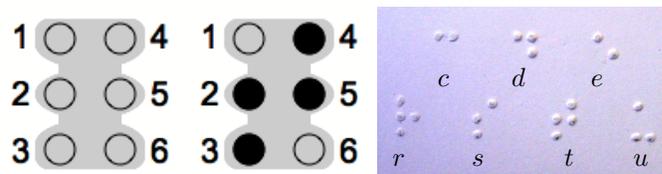


Figure 1: A schematic of a Braille cell (left) and the letter 't' (center). The black circles represent embossed dots while the light grey circles represent unembossed dots. A sample of Braille (right).

countries. According to the Mathru Educational Trust for the Blind in Bangalore, the main barrier in India's case is limited opportunities for education because parents and families of blind children often do not realize the possibility or value of educating their child. Even when the desire to educate is present, children may not receive sufficient guidance at home or in traditional schools because very few people are trained to teach Braille. Unfortunately, poorer areas tend to have both a disproportionately high number of blind people [World Health Organization, 2004] and fewer resources for educating them.

Furthermore, the traditional method of writing Braille itself creates formidable challenges to literacy. In developed countries, Braille is usually embossed with a six-key typewriter known as a Braille; these devices are fast and easy to use but also cost over US\$600 each [Perkins, 2006]. In developing countries, such devices are prohibitively expensive and Braille is almost always written with a slate and stylus as shown in Figure 2<sup>1</sup>. Using these tools, Braille is written from right to left so that the page can be read from left to right when it is removed from the slate and turned over. For blind children, learning to write Braille in this manner can be difficult. First, children must learn mirror images of all letters which doubles the alphabet and creates a disparity between the written and read forms of each letter. Second, feedback is delayed until the paper is removed and then flipped over and read. For young children, this delay can make Braille conceptually challenging since the act of writing has no discernible, immediate effect. It also takes longer for both the student and the

<sup>1</sup>Reprinted with permission from LightHouse for the Blind and Visually Impaired.



Figure 2: A Braille slate and stylus.

teacher to identify and correct mistakes and this slows learning. Finally, even the thick paper used to write Braille may be expensive or in limited supply. In sum, these challenges contribute to the problem of illiteracy among the blind in developing communities [Mathru School for the Blind, 2005].

We have collaborated extensively with the Mathru Educational Trust for the Blind in Bangalore, India, (see Section 6.1) a non-profit, all-volunteer organization dedicated to educating and rehabilitating the visually-impaired. As a result of discussions with the administration, teachers, and students at Mathru, we believe there is great potential to address these difficulties using an intelligent, low-cost, low-power tutor. To this end, we have created the Braille Writing Tutor shown in Figure 3 which consists of a low-cost, low-power electronic slate and stylus that mimics a regular slate and stylus and interfaces to a computer running the tutor software. The tutor monitors a student's writing and provides immediate audio feedback using text-to-speech synthesis that is tailored to the skill level of the learner and both highlights new concepts and reinforces skills that the student already has. It also acts as a diagnostic tool to help identify challenging areas for students.

There are four major applications of Artificial Intelligence in such a tutor. Firstly, we already use a text-to-speech synthesizer to provide spoken feedback to the learner. This is an essential component of the tutor as audio feedback must be both dynamically generated and is the only feasible method of communication with the blind learner. In the near future, we secondly hope to use contextual information to disambiguate series of dots that can have multiple meanings. Thirdly, we hope to model students' knowledge gains during learning to improve the tutor. Finally, we intend to compare what the student wants to write with what is actually written to provide adaptive feedback, tailored interventions, and control shaping.

This paper describes our first implementation of the Braille Writing Tutor and the results of a six-week pilot study of the tutor at the Mathru School for the Blind. In Section 2, we describe related work on automated tutors and teaching aids for the blind. We describe the Braille Writing Tutor in Section 3 and discuss its hardware and software components. We then present our pilot study with results and lessons learned in the field in Section 6. Finally, we conclude with a discussion of the Braille Writing Tutor and outline future directions of research.

## 2 Related Work

A number of intelligent tutors exist for a range of subjects and skills including math [Koedinger *et al.*, 1997], English reading [Mostow *et al.*, 1994], speaking [Bunnell *et al.*, 2000], and computer programming [Weber and Brusilovsky, 2001]. Encouragingly, many of these tutors have achieved success in the classroom. Nevertheless, they have limited impact on our goals for a number of reasons. Firstly, of course, they are not tailored to writing. Secondly, they require sight and use written instruction extensively in the tutoring process; in contrast, a tutoring system for the blind usually depends heavily on audio feedback. Thirdly, this limitation means that most existing automated tutoring systems for the blind are fairly simple (e.g. the Talking Braille Tutor® teaches only individual symbols [Peaco, 2004]) and cannot teach complex skills such as writing using a slate and stylus. A notable exception is the Speech Assisted Learning (SAL) device which tutors reading and math using a stand-alone refreshable Braille display [Chamot, 2006]. Fourthly, like SAL (which is US \$4600) and the Talking Braille Tutor (which is US \$300), most assistive technology is prohibitively expensive because the number of blind people who could potentially access it is very small. Finally, most such technology depends upon computers which are unavailable among most our target population. We believe that the LISTEN reading tutor [Mostow *et al.*, 1994] which listens to children read aloud has the most relevance to our work as it uses an alternate medium of interaction (spoken words) and teaches a basic literacy skill (reading). Moreover, it employs many of the Artificial Intelligence techniques we intend to additionally incorporate into our tutor. Nevertheless, the need remains for a writing tutor specifically tailored to meet the needs of the blind in developing countries.

## 3 The Braille Writing Tutor

This research is aimed at developing an intelligent tutoring system that teaches writing skills to the blind in developing countries. Our goal is to design a tutor that mimics the experience of writing with an ordinary slate and stylus but that also provides a variety of scaffolding methods to eliminate aspects of a slate and stylus that hamper different stages of the learning process. We identified these scaffolding methods (presented in Sections 3.1 and 3.2) in close collaboration with teachers at the Mathru School for the Blind; some are direct results of the field study which we discuss in Section 6 and remain as future work.

Although the tools for writing Braille have improved significantly in developed countries [Hinton and Connolly, 1992] the slate and stylus is essentially the only writing implement available to a blind person in the developing world. We deliberately aim to improve the learner's use of the slate and stylus rather than attempt to teach the use of more modern and expensive tools as these tools will not be available to the students once they leave the school.

Our current implementation is designed to quickly test the basic feasibility and utility of the tutor. The tutor consists of an electronic slate and stylus known as the E-Slate which monitors the students' writing and transmits data in real time to a computer. The software tutor resides on an external PC;

it interprets the data from the E-Slate and uses text-to-speech synthesis to provide immediate audio feedback to the user. We describe the hardware in Section 4 and the software in Section 5.

### 3.1 Scaffolding for the beginning student.

The fundamental idea behind Braille is that there are six dots in each cell and that embossing different combinations of dots produces different characters which can be read on the reverse side of the paper. For small children in particular, the delay between writing and reading the result, which may be several minutes, makes writing Braille conceptually difficult. The delay is long enough that it is difficult to remember exactly which actions produced the dots that now appear on the paper. Indeed, to some beginners there appears to be no effect whatsoever of pressing the stylus into the slate: they cannot understand that the indentations on the paper were created by the earlier embossing process. This stands in marked contrast to sighted children who can immediately see the results of putting pen to paper.

Other aspects of the slate and stylus also interfere with learning. Firstly, a Braille cell is very small: the distance between the centers of adjacent dots is about 2.5mm and the distance between adjacent cells is about 6mm. Although this small size minimizes space requirements and improves speed in the skilled reader, small children have difficulty perceiving that there are six dots to a cell and distinguishing between the different dots. Thus, even when they know that the letter ‘b’ consists of dots one and two, they cannot produce the letter. Secondly, reading requires tactile acuity that may not be fully developed in a young child; for example, she may not yet be able to distinguish between the letter ‘b’ (dots one and two) and the letter ‘k’ (dots one and three) and therefore cannot interpret the results of embossing. Thirdly, significant force is required to emboss Braille paper and the children soon tire. This is particularly true for children who are weak from poor nutrition. Collectively, these features not only make learning difficult, they also create significant frustration and discourage young children from writing.

We can address each of these problems in our tutor. Firstly, we wish to provide feedback to the child as she touches the stylus to the slate. For the beginner, the tutor speaks the number of the dot that was pressed, one through six. This occurs immediately and thus eliminates the problem created by the delay between writing and reading. For the slightly more advanced student, the tutor also speaks individual letters. This feedback simultaneously reinforces the student’s grasp of the alphabet: for example, the student hears “one, two, four – h” which refreshes their knowledge of the dots that make up each letter. Additionally, since the result is spoken, it circumvents the problem of tactile acuity. Secondly, by using a jumbo slate in which the dots are a centimeter in height and several centimeters apart, students can learn to write even if they have yet to acquire the fine motor skills required by a regular slate. This is analogous to the very large ruled paper used by sighted children. Thirdly, by requiring only contact between the slate and the stylus to signify the embossing of a letter, students can write even if they do not have strength to emboss real paper. Finally, by providing adaptive feedback

and control shaping, the student is able to concentrate on areas that are particularly challenging for him or her.

### 3.2 Scaffolding for the advanced student

The advanced student who already understands the concept of Braille and can write letters must now learn to spell and write words and sentences. For these students, we begin the process of fading by gradually replacing dot and letter feedback with word and sentence feedback. We can also replace the jumbo slate with a normal-sized slate that requires full embossing acuity and pressure. We add further scaffolding in the form of feedback and tutorials for math symbols, punctuation, and contracted forms of Braille. Again, by providing adaptive feedback and control shaping, the student can receive a tailored learning experience.

### 3.3 Design Goals

During our initial design phase we identified a number of hardware and software goals that we had to meet in order to create an effective tutor system:

- *Low-Cost* Unlike other tutors, ours must be affordable to members of the base of the economic pyramid who live on less than US\$2 a day. We hope to make it affordable to every village or rural school even if it cannot be affordable to individuals. Our target price is US\$20 per unit for systems requiring an external computer and US\$40 per unit for systems with embedded text-to-speech hardware that can operate without a computer.
- *Low-Power* In developing countries, electricity may be unreliable, in limited supply, or simply unavailable. The tutor must maximize the resources available, be robust to unreliable power, and be able to be powered by alternative sources. Our target power consumption is 300mW, or enough to operate for about 50 hours on 4 AA batteries.
- *Robust* The tutor’s hardware components must be rugged enough to be extensively used and abused by students for a long time.
- *Easily Operated* The tutor must be easily and independently operated by a blind person. This means that both the hardware and the software must be accessible to someone with little or no computer literacy or experience with electronics. It must also provide guidance that can be utilized without the presence of a teacher.
- *Easily Understood* The tutor’s speech module must be understandable given the age and background of the learner. Depending on the circumstances, it may use local languages, local dialects, and age-appropriate voices.
- *Locally Maintainable* The tutor must be designed with easily available components so that if any of the electronic components fail, repairs can be made on-site or nearby. This means using commonly available materials and manufacturing techniques.

## 4 E-slate Design

We designed the E-Slate in collaboration with Mathru over a six month period at Carnegie Mellon University; the design and assembly of a field-testable prototype constituted a V-Unit, an independent study course offered through the TechBridgeWorld initiative [TechBridgeWorld, 2006]. The E-Slate was redesigned four times; after each iteration we gathered feedback from local engineering and human-computer interaction communities and made improvements. For example, one major improvement was the addition of a second line of Braille cells in the input area after teachers at Mathru indicated that switching lines was one of the most difficult concepts for students to grasp.

### 4.1 Design Challenges

The most challenging aspect of the design of the E-Slate was to match it as closely as possible in feel to a regular slate and stylus while meeting our low-cost and low-power goals; all components were carefully evaluated for cost, robustness, and wide availability. As shown in Figure 3, the input area of the E-slate consists of two rows of 16 Braille cells each and is integrated directly into the circuit board to maximize robustness and minimize cost. A cutout from a normal plastic slate is placed over top of the two Braille rows to give students the exact same feel as when writing on a standard slate. We used an extremely low-cost and low-power microcontroller, the Atmel ATMEGA88 [Atmel, 2006] in conjunction with a custom resistor network decoding circuit to handle the sensing of stylus location in the input area. If the stylus is in contact with any dot in the input area, the Atmega88 senses which dot in which cell the stylus is contacting and transmits the information to a computer over the serial port. The stylus is a standard Braille stylus modified to connect it to the slate via a wire soldered to its metal tip.

### 4.2 Hardware Features

A small speaker and four buttons provide a basic interaction modality between the student and the E-slate, even when it is not connected to a computer. The speaker emits a tone whenever the stylus makes contact with a dot in a Braille cell, with each dot being mapped to a different musical note. The four buttons activate and deactivate several features. To save power while allowing for visual debugging, button 1 toggles the heartbeat LED. Button 2 mutes the speaker so that more advanced students can use the E-slate without tonal feedback. Button 3 reverses the direction of the text, allowing students to choose between writing right to left (as is typical when writing with a standard slate and stylus) or left to right (which is the direction Braille is read in)<sup>2</sup>. Button 4 was included to allow an unprogrammed hardware input to the tutor software - it simply sends an acknowledgment to the computer when the button is pressed. The stylus connection port also contains two additional inputs for buttons located on the stylus. Currently, one button is placed on the stylus for students to indicate the completion of a character or word.

<sup>2</sup>During our field study, we found that this feature was not useful and disabled it.

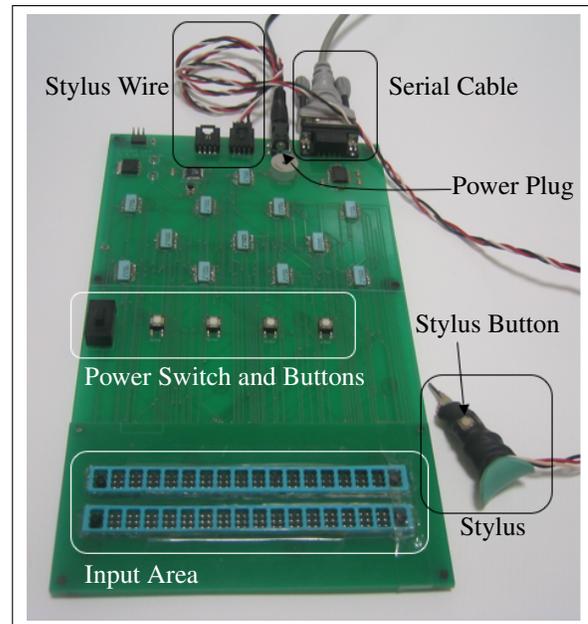


Figure 3: The prototype E-Slate taken for field testing at the Mathru School for the Blind.

### 4.3 Power

We initially considered several off-grid methods of powering the E-slate: solar cells, batteries powered by a solar charger, and a hand crank to charge batteries. Unfortunately, all of these options were more expensive than the E-slate itself! We decided that since the current iteration of the E-slate requires a computer powered by the electrical grid to be useful, expensive off-grid solutions should be explored at a later time. The E-slate is powered by an inexpensive AC/DC wall adapter which has an input range of 100 to 240 VAC at 50/60 Hz, and outputs up to 300 mA at 6 VDC. This input range is globally compatible with all electrical grid standards, and so the only adaptation that must be made to use it in different countries is to purchase an appropriate plug adapter.

## 5 The Tutor Software

The tutoring software was developed in close coordination with the teachers at the Mathru School for the Blind and was tailored to the needs of the students throughout the course of the field study. Together, we outlined three main stages of skill acquisition for the Braille student. The first step is to understand the concept of Braille and to emboss the six dots in a cell. The second step is to learn the unique combinations of dots that make up each letter and write the alphabet. The third step is to put letters together into words, put words together into sentences, and learn math symbols and punctuation. We created three different tutoring programs with emphasis on each of these skills and with capabilities to transition to the next skill.

Although Braille forms exist for many languages including the students' primary languages of Kannada and Tamil, they are taught Braille in English first because it is the standard

approach and relatively simple (many Indic languages have more than  $2^6$  characters and a single character may require more than one cell). Therefore our software tutor is currently limited to English Braille.

The software tutor receives input from the E-Slate regarding the learner's actions on the slate, where an "action" is either a contact between the stylus and the slate or a press of one of the five buttons. The tutor interprets these actions using a state machine and provides feedback tailored to the skill being learned.

### 5.1 Second Standard Braille Writing Tutor.

The second standard tutoring software meets the scaffolding needs mentioned in Section 3.1 of the beginner student learning the concept of six cells. Whenever the stylus is touched to the slate, the tutor speaks the position of the dot that was touched. This helps the student understand the cause and effect relationship between embossing on a slate and creating letters. It also teaches the spatial relationships between the different dots. The second standard tutor additionally has capabilities smoothly transition to teaching and reinforcing the alphabet once the six-dots concept is learned: when the student presses the button on the stylus, the tutor will speak the letter written on the current cell. For simplicity, none of the other buttons on the E-Slate have any effect in this tutor. For the second standard tutor, we used a Mathru teacher's digitized voice for the dot and letter feedback. Firstly, there is a finite number of letters and positions so digitizing the feedback was feasible. Secondly and more importantly, we expect that younger children using the second standard tutor may not be familiar with foreign accents and would feel more comfortable and learn faster if they heard their own teacher's voice.

### 5.2 Third Standard Braille Writing Tutor.

The third standard tutor in part meets the scaffolding needs of advanced students. The third standard tutor retains the position and letter feedback for reinforcement and spelling practice. It encourages speed by not requiring a student to press the stylus button to register a letter; instead, a letter is registered whenever the student transitions between cells. It additionally provides word feedback by keeping a character history and uses text-to-speech synthesis to speak the last word written when a student "double-clicks" the button on the stylus. For the TTS engine we use Cepstral's® female American-English Callie voice [Mitchell, 2006] which they donated to the project. To augment the word feedback, we provide functionality both to erase and then correct previously-written letters and to spell the letters in the last word. This allows students to work on spelling as well as writing.

### 5.3 Fourth Standard Braille Writing Tutor.

The fourth standard tutor provides the remaining scaffolding for the advanced student. Here, we fade the position feedback with the idea that the learner is familiar with the positions and finds such feedback cumbersome. This tutor additionally provides feedback on the last sentence written using the same text-to-speech engine. It also recognizes math symbols



Figure 4: Students at Mathru use the Braille Writing Tutor.

and punctuation which may require multiple cells per symbol, which have two symbols mapped to the same letter, or both. The tutor uses a decision tree to determine which symbol is intended.

## 6 Field Study

We conducted a six week pilot study at the Mathru School for the Blind in Bangalore, India to evaluate the feasibility and utility of the tutor in the field and to obtain feedback on future work.

### 6.1 Mathru School for the Blind

The Mathru School is residential and currently has 44 children enrolled in grades one to six. In addition to providing the standard curriculum for the state of Karnataka, Mathru teaches daily living skills such as mobility and food preparation, offers vocational training such as computer classes, provides medical care, and encourages talent, personality development, and self-confidence. Six of the eight teachers at Mathru are themselves blind or visually impaired. Additionally, most of Mathru's students come from the very poorest of Karnataka's villages where they may previously have had no access to running water or electricity, much less computers and electronics. We have chosen Mathru in part because its students are representative of the community we hope to ultimately reach.

### 6.2 Formal Results

We developed the concept of the Braille Writing Tutor in close coordination with teachers and administrators at Mathru. We are interested in evaluating our current implementation of the tutor along a number of metrics which we categorize into two groups: usability and effectiveness. From August 5<sup>th</sup> to September 15<sup>th</sup> 2006, we brought the tutor to Mathru for a pilot study. Our target group was students in grades two and three as they had begun to learn Braille but had not yet mastered it. This group consisted of six students in each grade for a total of twelve students. Ordinarily they had Braille class in four one-hour periods each week; for our study, they used the Braille Writing Tutor for forty minutes

of the one hour and use a regular slate and stylus during the remaining twenty minutes. Although we focused our study on these twelve, we allowed any interested student to use the tutor.

### Usability

We are interested in how easy or difficult the tutor is to use by both the teachers and the students. Some questions include:

- *Hardware assembly.* What are the minimum abilities required to assemble the hardware? How long does it take to learn how to assemble it? How long does it take to assemble?
- *Software installation.* What are the minimum abilities required to install and then start the software? How long does software installation take?
- *Tutor use.* How long does it take to learn how to start the tutor? What are the minimum abilities to start the tutor? How much and what type of instruction is required to learn how to use all the functionalities of the tutor?

We evaluated these features by observing both the teachers' and the students' use of the tutor. Hardware assembly involves plugging one end of the power adapter into a wall socket and inserting the other end into a socket on the E-Slate, connecting the serial cable between the E-Slate and the PC, and connecting the stylus to the E-Slate. We found that the blind teachers and students could only connect the power supply; connecting the serial cable and the stylus was impossible for them because the connectors are small and keyed. We trained a low-vision teacher with prior computer experience to successfully connect the serial cable and power in a single 30 minute training session but the stylus was simply too small to manipulate. Ultimately, this teacher was able to connect the power supply in under a minute but took 2-3 minutes to distinguish between the male and female ends of the serial cable, find the serial port on the back of the computer, and connect them. These difficulties highlight that we must completely re-design the hardware connection method to make assembly possible for our target group.

Software installation was also challenging as it involved a number of complex steps that required familiarity with advanced features of the Windows operating system. In the end, we installed all the software ourselves and successfully trained sighted teachers with significant prior computer experience. This highlights that software installation must also be redesigned significantly to install all components in a single step.

Nevertheless, once the components were installed and connected, the students could find the switch and turn on the E-Slate after only five minutes of training. The only difficulty was that the smaller children had difficulty determining when the switch was in the on position and when it was in the off position – we believe a larger, labeled switch would fix this problem. The older students (4<sup>th</sup> standard and higher) who had prior experience using a PC were able to start the Braille Writing Tutor software on their own with just minutes of instruction; younger children needed a teacher to do it for them.

At the end of the field study we also conducted a survey of the target group regarding usability. With the help of a

teacher, we asked the children to agree or disagree with the following statements.

1. I found the Braille Writing Tutor difficult to use.
2. It took a long time to learn how to use the tutor.
3. I cannot understand the voice used by the tutor.
4. I find it difficult to distinguish between the buttons on the E-Slate.

To reduce the likelihood that the students would answer favorably simply out of respect or an eagerness to please, we explained to them that honesty was very important and had the teachers administer the survey when we were away from the school. Overall, most students (10 of 12) found the tutor easy to use; the remaining two students were in the second grade and had significant difficulty with the overall concept of Braille. Indeed, they had difficulty understanding some of the questions in the survey. Again, most students found it easy to learn how to use the tutor and all could understand the voice used by the tutor, despite that the text-to-speech synthesizer used an adult female American voice. We suspect this may be because they are accustomed to the JAWS screen reading software which uses a similar male voice. Finally, roughly half of the students (5 of 12) found it difficult to distinguish between the buttons on the E-Slate. We believe that labeling the buttons and giving them unique shapes will alleviate this problem.

### Educational Impact

Our fundamental concern in this field study was to understand the educational value and impact of the tutor. Some questions include:

- *Attitude towards tutor.* What is the teacher's response to having the tutor supplement classroom work? What is the students' attitude to the tutor? Do they believe it will help in learning to write Braille?
- *Enthusiasm for writing.* How does the tutor affect students' interest in learning to write Braille?
- *Writing ability.* How does the tutor affect students' ability to write Braille? Are they faster at writing on a regular slate and stylus? Do they make fewer mistakes?

From our discussions with them, the teachers' response to the tutor was very positive: they believe the tutor can help the students overcome their difficulties in writing. Moreover, the teachers are eager to continue having the tutor in the classroom and have requested that we provide one E-Slate for each PC in the school. Their involvement in improving the software also highlighted their belief in the value of the tutor and they are further interested in bringing the tutor to other schools for the blind.

We evaluated the target students' attitude towards the tutor through an interview at the end of our six-week study. We asked them to agree or disagree with several statements:

1. I find the tutor useful.
2. I dislike using the tutor.
3. I prefer writing on a regular slate to writing on the E-Slate.

4. I want to continue using the Braille Writing Tutor.
5. I think the tutor will help me in learning to write Braille.

As before, nearly all of the students (10/12) found the tutor useful and believed it would help them in writing Braille; the remaining two students were the same ones that found the Braille concept challenging and had difficulty understanding many of the survey questions. However, all students strongly disagreed with the statement “I dislike using the tutor” and emphatically agreed with the statement “I want to continue using the tutor.” Finally, nearly all students (10/12) preferred writing on the E-Slate to the regular slate (primarily because they enjoyed the interaction and the voice); the ones that did not were the youngest students who had difficulty finding the button on the stylus. While this indicates a positive response to the tutor, there is concern that students will adopt the E-Slate completely because it is easier to use and more interesting. We believe that this can be avoided in the school setting by having frequent exercises on a regular slate and stylus.

We evaluated the students’ enthusiasm for writing Braille by observing which students wrote Braille outside of the Braille class period and the frequency of this use. We found that almost every student used the tutor outside of class at least once a week – only three of the students used it only during class. Interest varied from student to student: a few used the tutor on an almost daily basis while others used it once or twice a week. However, students’ interest in writing Braille extended only to using the tutor; it was rare to find students using the slate and stylus outside the classroom both before the introduction of the tutor and during the field trial.

Finally, we were interested in how the tutor affected the students’ writing ability. We forwent the opportunity to have a control group in favor of allowing students unlimited and unstructured access to the tutor to measure their interest and responsiveness. We further wanted to improve the software throughout the study in response to the students’ use. Therefore, we measured all twelve target students’ proficiency in Braille once at the beginning of the study and once at the end and evaluated their improvement by assessing the skills learned. Although it is thus difficult to attribute improvements solely to the tutor, we can determine its impact somewhat by understanding students’ prior abilities. We tested how many cells the students could fill in with all six dots embossed (which we call the “six-dots test”) and how many letters they could write (which we call the “alphabet test”) in a fixed period of time. We also evaluated the number of mistakes made during the test; a mistake was defined as erroneously omitting or adding a dot or failing to leave a space between letters.

We can categorize the students into three groups based on a qualitative analysis of their pre- and post-trial test results. Four of the twelve students (call them Group A) demonstrated complete understanding of the Braille concept and could write the alphabet quickly and with few mistakes *before* we began the study. The tutor mainly provides advanced practice for these students. The second group (Group B) consisted of five students who lacked proficiency before the study but attained demonstrable proficiency by the end. The third group consisted of three students (call them Group C) who



Figure 5: The teachers use the Braille Writing Tutor at the tutor station we set up in the computer lab.

did not understand the concept of Braille and showed a significant lack of proficiency *both* before and after the study. We are interested in these last two groups to understand how the tutor may have helped those in Group B and why it did not help those in Group C.

Two of the five students in Group B (the group showing improvement) understood the concept of Braille before the study began but made frequent mistakes. At the end, they wrote significantly faster and made far fewer mistakes. Specifically, one student’s abilities jumped from writing seven letters with four mistakes to writing thirteen letters perfectly, and the other student’s abilities jumped from writing 23 letters with eight mistakes to writing 26 letters with one mistake. For these students, we suspect that the improvement was probably just the natural result of practice. Although the Braille Writing Tutor may have sped up their learning in comparison to using a regular slate because it increased their interest in writing, we cannot confidently make this claim without a control group.

The remaining three students in Group B made significant *conceptual* advances: in the first proficiency test they showed a distinct lack of understanding of Braille and were unable to emboss all six dots in a single cell. By the end of the study, two of the three students each wrote five letters with no mistakes and the other student complete the six-dots exercise in three cells. From our discussions with their teachers, we believe this is probably a direct result of getting immediate feedback from the tutor as these students had not demonstrated any understanding of Braille in the several months prior to the study.

Although it is not clear why Group C did not benefit from the tutor (or from a month of Braille practice overall), our discussions with the teachers lead us to believe that they may not yet be developmentally ready to learn Braille. That is, we believe that members of Group C may have multiple disabilities/may need to develop basic social and personal skills.

### 6.3 Additional Observations

Several of our observations during the field study are anecdotal and offer insight into the impact of the tutor on the students

and teachers at Mathru.

### **The Tutor as a Diagnostic Tool**

One student's writing usually consisted of a single cell with all the dots embossed, regardless of the assignment. Thus, it appeared that he had no conceptual understanding of Braille though he had been in Braille class for a few years. To the teachers' delight, this student began writing Braille as soon as he was asked to use the tutor. The inconsistency is that apparently this student had always been writing every letter in the same cell, thus creating the completely embossed single cell. This was not evident to the student's teacher because the teacher herself was blind and could only feel the results of the writing on the paper; moreover, the student was unable to communicate well and explain what he was writing. Because the Braille Writing Tutor interprets letters after the student presses the button on the stylus, it did not matter that they were all in the same cell. Additionally, the teachers were able to hear the result of this student's writing immediately and soon realized that there was a gap in the student's understanding. In this way, the tutor acted as a diagnostic tool: it highlighted the students' unique difficulties and was able to provide insight to the teachers.

### **Skilled Users' Interest**

Although the tutor is designed for beginner Braille students, we frequently found older students and even the teachers using the tutor in their spare time simply out of interest (see Figure 5). Though highly proficient in Braille, they simply enjoyed hearing the tutor speak their words and thoughts back to them. This highlights to us the attractiveness of any device that speaks and, more importantly, says whatever the user wants it to.

### **Understanding Features**

When we first introduced the tutor to the students, we found that even the most proficient and fast writers wrote very slowly and gingerly on the E-Slate. Concerned that this indicated a major design flaw, we engaged the students in a discussion about their use of the tutor. We found that the students were *afraid* of the E-Slate: they could feel the wires leaving the stylus and were very concerned that they would receive an electric shock if they were not careful. They also believed the hardware was delicate and would break if they were not gentle. This highlighted to us the importance of explicitly highlighting features of the slate (in this case, safety and robustness) as well as having these features. The students speed and confidence significantly increased after we explained and demonstrated that the slate was robust and benign.

## **7 Conclusions**

Overall we believe the Braille Writing Tutor has great potential to inexpensively and effectively speed the education of a large number of blind students in the developing world. Our experiences thus far have been enormously positive, and we look forward to improving the tutor based on the lessons we have learned at Mathru, and expanding the program as much as possible.

## **7.1 Future Work**

### **Hardware**

Although we succeeded in developing a hardware slate and stylus that met many of our design challenges, we are considering a number of improvements to the E-Slate. As discussed in Section 3.1, a 10x scale size Braille cell would allow beginner students to understand the concept of Braille in a simpler way and to become comfortable spelling letters before they learn to transition between cells or write words. We would also like to provide a cover over the electronics and Braille labels for important areas of the slate and use uniquely-shaped buttons for easier identification. We expect to make these improvements by February 2007.

In the longer term, we believe a stand-alone device is essential to meet our design goals of usability in remote locations and among the very poor. This device would have the speaker and speech synthesis module and the tutor software embedded onto a mixed DSP/microcontroller. The tradeoff is that it may cost significantly more than our current E-Slate. We are also considering using an FPGA with an integrated microcontroller to reduce the number of discrete components on the E-slate and thus lower component and assembly costs.

### **Software**

The tutor software provides a number of scaffolding methods that we believe already accelerate the students' writing abilities. Nevertheless, there are a number of areas of improvements. We hope to use Artificial Intelligence techniques to disambiguate different Braille characters, model students' skill acquisition to offer better tutoring, and provide adaptive feedback and use control shaping to create a tailored learning experience. We would also like to tailor the speech feedback to the needs of the students. First, we hope to use age- and accent-appropriate English text-to-speech synthesizers to make the system more understandable and more engaging. Secondly, would like to extend the tutor to other languages; while encoding the Braille script for other languages is relatively easy, this improvement does depend on the availability of a TTS engine in the language of interest.

In the longer term, we would also like to use the E-Slate as a regular input device that can interface to word processors when a PC is available so that text can be stored and printed out later.

### **Field Testing and Deployment**

There are a number of avenues for future field testing as well. Firstly, we would like to make the aforementioned improvements and conduct another, more formal field study with more students and using a control group over a longer period of time. We would also like to take the tutor to other schools. Within India, Mathru has agreed to be our ambassador and contact other schools for the blind and teach their staff how to use the tutor. Globally we are investigating contacts in Brazil and Russia and would like to expand the program to any location where it could be of use.

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