A Multimodal Collaborative Handwriting Training System for Visually Impaired Students

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Abstract

The spatial and motor skills used for handwriting are particularly difficult for visually impaired people to develop. These skills are required in order to sign an aesthetically pleasing and repeatable signature, which is often required for documents such as legal agreements and job applications.

In a previous study, a system called McSig 1.0 was designed to teach visually impaired students how to write letters and eventually, a signature. McSig 1.0 is designed for the teacher and student to work together. The system recreates the movement of the teacher's pen for the student. The student holds a pen which is attached to the mechanical arm on a PHANTOM Omni haptic device. The teacher scribes a letter shape on a Tablet PC screen. As the teacher's pen moves, software causes the mechanical arm to move the student's pen around the trajectory of the stroke, so that the student's hand is guided through the formation of the letter. At the same time, the stereo pan and pitch of a sound tone are altered to express the movement of the pen in the x and y axes, respectively. The tip of the student's pen moves over a tactile plastic sheet. The sheet is scored, leaving a tactile ridge that the student can feel with the non-writing hand.

In this project, a system upgrade was carried out to improve this technology. The resulting system is McSig 2.0. A longitudinal study was carried out with three visually impaired students to test the effectiveness of the improved system.

The system upgrade was carried out to improve the support for the task of learning a signature. Information about the shortfalls of the McSig 1.0 system during a previous study, the literature on teaching children to write, our own observations of McSig 1.0 and practical requirements for a longitudinal study provided requirements for improvements. The system was designed and developed in collaboration with a visually impaired adult. The improved system was evaluated using the Cognitive Dimensions framework.

A longitudinal study was carried out with three visually impaired students. Over a series of lessons, each student was guided through exercises with McSig 2.0 with the goal of teaching each student a signature. The study demonstrated that McSig 2.0 can greatly assist visually impaired students to learn a signature. Two of the students achieved the goal of developing a signature. They demonstrated considerable improvement on their original handwriting skills, and after 10 lessons were able to carry out a signature without assistance. The third student was able to quickly learn letter shapes after having them demonstrated with the McSig 2.0 system, and could form several of the letters using pen and paper.

As tactile technologies become commonplace, appearing even in mobile phones, the McSig system may provide useful insight into the use of non-visual feedback for a variety of applications.

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Chapter 1

Introduction

1.1 Motivation

For a visually impaired person, learning how to sign a signature that is aesthetically pleasing and can be repeated consistently is a difficult task. The student must learn basic spatial concepts, the shapes of the letters and the motor skills needed to form them. Without the usual visual feedback received while learning to write, there are a number of unique challenges to overcome. For example, crossing a lowercase *t* is a particularly difficult task because the student has no visual feedback to use to reposition the pen for the crossing stroke. Writing the signature in a straight line and at an appropriate size are further challenges.

Many congenitally blind students do not learn how to sign a signature, yet it is necessary in many everyday scenarios. Business letters and legal contracts are examples of where a signature is required.

Existing tools that might be used for teaching letter shapes are helpful but not sufficient. For example, students could explore stencils, plastic letters or pipe cleaner letters to find out about the shapes of letters. But these tools do not teach the student the motor skills needed to form the letters with a pen.

A conventional approach to teaching handwriting to visually impaired students is for a teacher to physically hold and guide a student's hand around letter shapes. Haptic guidance technology offers possibilities for more accurately controlled guidance that can also be combined with other non-visual feedback.

Learning could be encouraged by providing feedback in a multimodal fashion, presenting letter shapes in an engaging and interesting way. The tactile modality is an important modality for visually impaired students. It is a familiar mode of interaction, being used in Braille and in educational tools such as tactile maps. Another modality, kinaesthetics, is employed when letter formation is demonstrated to a student. The sound modality offers further opportunities for communicating and instructing about letter formation.

1.2 Thesis Objectives

McSig 1.0 (Plimmer, Crossan et al. 2008) is a multimodal, collaborative teaching and learning environment, designed to assist visually impaired students to learn letters and eventually, a signature. For this study, the research has two main goals.

The first goal is to improve the McSig 1.0 technology to provide more sophisticated support for the signature-learning task. An upgrade is to be carried out on McSig 1.0, resulting in an improved system, McSig 2.0.

The second goal is to explore the usefulness of the technology. A longitudinal study is to be carried out with three visually impaired students. This is to consist of a series of lessons, with the goal of teaching each student a how to sign a signature.

The upgrade should alleviates problems with McSig 1.0, consider the best-practice techniques for teaching children to write and make the system practical for use during lessons.

Case studies from the longitudinal study are to be analysed to determine the ways in which the system appears to support the task of learning a signature.

1.3 Our Approach

The research comprises of two main strands. The first is the requirements gathering, design, development and evaluation of a system upgrade. The second is the undertaking of a longitudinal study involving three visually impaired students.

The requirements for the system upgrade are gathered from four sources. First, findings from the McSig 1.0 study (Plimmer, Crossan et al. 2008) are used. Second, the literature on teaching children to write is consulted. Our own observations about the effectiveness of the McSig 1.0 system (Plimmer, Crossan et al. 2008) contribute to the requirements. Requirements also arise from the need to prepare the system for a longitudinal study.

The development of the system is carried out using a participatory design and development approach (Dix, Finlay et al. 2004). Informal evaluation sessions with a visually impaired adult allow design options to be discussed. The visually impaired adult is a close match to the end-user group.

The evaluation of the system is carried out using the Cognitive Dimensions framework (Green and Petre 1996). This allows us to create a profile of cognitive aspects of the system.

The longitudinal study is carried out with three students. Ten lessons are carried out with each student, with the purpose of assisting each student in learning how to sign a signature. Video records of lessons, screenshots, plastic tactile sheets and written notes of observations form a rich pool of qualititative data. A detailed case study is presented for each student. We discuss the students' progress and what the study reveals about how McSig 2.0 appears to contribute to the students' learning.

1.4 Hardware Used

The PHANTOM Omni (shown in Figure 1) is a force feedback device which is commercially available from SensAble Technologies Ltd (http://www.sensable.com/).

The device has motors that can constrain or move the device in the x, y and z dimensions. A user can hold the pen-shaped end effector. The device can interact with software which specifies various constraints or provides instructions. In a possible scenario, the user can actively move the device and the end effector will be stopped upon reaching a certain position or plane. This effect can be used to replicate the feeling of a surface or three dimensional object. The device can be controlled to the point that the illusion of touching a textured object can be created. Another possible use is to provide the device with position information to specify where its end effector should move. If a trajectory is specified, a user can have their hand guided through a movement. This is the way in which the device is used within McSig.

Figure 1 The PHANTOM device can be used to guide a user's hand through a trajectory.

The Tablet PC provides a means of digitising pen stroke information. An ink digitiser on the screen is capable of capturing numerous features relating to pen strokes. The speed, position and pressure of the pen along a pen stroke can be captured at a high resolution.

1.5 Thesis Outline

In the "Related Work" section, an outline of key principles for teaching handwriting is presented. The basic workings of McSig 1.0 are explained. Various approaches to providing feedback in the non-visual kinaesthetics, sound and tactile modalities are surveyed. The success of the various techniques is discussed.

The "System Upgrade" section explains the methodology used and the requirements for the upgrade. The implementation of new features is then discussed.

The "System Evaluation" section explains the Cognitive Dimensions framework and its applicability as an evaluation tool for McSig 2.0. A summary of a Cognitive Dimensions evaluation of McSig 2.0 is presented. Conclusions are drawn on the evaluation.

The "Longitudinal Study" section discusses the approach and methodology for a longitudinal study with three visually impaired students.

The "Results" section presents a case study for each of the three students, showing detailed observations from lessons carried out during the longitudinal study.

The "Discussion" section discusses the results of the longitudinal study with respect to the learning experience. A review of the McSig technology is also presented.

In the "Conclusions", an overview of the key parts of the research is presented. The findings of the research are summarised. Suggestions for future work are also given.

The "Appendices" section contains an operating manual, which provides information for the teacher on how to operate the McSig 2.0 system. The information and consent forms for ethics are included. A calendar of lessons with the students is also shown.

1.6 Definitions

Visually impaired This term can be used to describe those who are both partially sighted and totally blind, congenitally or otherwise. In many instances in this thesis, the term is used with reference to those who are both *totally* and *congenitally* blind, as this is the target group of users.

Chapter 2

Related Work

Techniques for teaching handwriting to sighted children are well established. However, the usual instruction and feedback while learning to write is visual. For teaching visually impaired students, we have the unique challenge of employing alternative modalities to provide useful information and feedback. From among the human senses the kinaesthetic, sound and tactile modalities can all be used to provide such feedback. In Section 2.1, literature on teaching children to write is examined to highlight fundamental concepts that need to be considered in non-visual teaching. In Section 2.2 we describe a multimodal system, McSig 1.0, which uses three non-visual modalities to teach visually impaired students handwriting. McSig 1.0 formed the base technology for this project. Section 2.3 explores related work in the three non-visual modalities used in McSig: sound, kinaesthetic and tactile.

2.1 Teaching Handwriting

Writing is a motor skill and there is much research in understanding how people may learn a motor skill. Work from the domain of teaching sighted children to handwrite also provides useful guidance when teaching the same skills to visually impaired students. Information about ergonomics, preparation for writing, and the way to structure the learning process provides a general approach. The importance of recognising and catering for the needs of the individual child has also been recognised (Arter, McCall et al. 1996).

Schmidt's Schema Theory in motor learning (as cited in Yokokohji, Hollis et al. 1996) talks of two states of a user's memory. A "recall" memory is that memory which allows the enacting of a movement. A "recognition" memory allows the user to evaluate the feedback they receive. As a student attempts to learn a motor skill, it is therefore important that they receive sufficient feedback. The ability to evaluate feedback is limited during quick movements. This emphasizes the need to carry out relatively slow movements during motor training for visually impaired people, where the evaluation of haptic feedback is particularly vital.

Motor skill training techniques can sometimes utilise additional feedback and cues to assist the learner. This can be seen to be at odds with the user learning how to perform the skill independently (Feygin, Keehner et al. 2002). It has been suggested that certain stages of the learning process may benefit more where additional cues are involved. Three stages of the learning process have been described by Fitts (as cited in Feygin, Keehner et al. 2002): cognitive, associative and autonomous. During the cognitive stage, a learner gains a general understanding of the target task. The associative part of learning involves a user discovering the means of achieving the task. These first two stages may benefit the most from learning involving additional cues. The final autonomous stage is where the learner gains the ability to successfully carry out the target task without any help (Feygin, Keehner et al. 2002).

Writing motor skills are refined and developed from an early age by using a pen to scribble, colour in or draw a picture. The literature on teaching sighted children to write emphasises the need to develop the control of large approximate arm and hand movements. These are seen as a necessary pre-cursor to developing the more finely controlled motor movements used in writing (Arter, McCall et al. 1996). Painting is one suggested activity to develop these large movements (Taylor 2001).

Ergonomics are important during writing. The literature emphasises the need to maintain an appropriate posture while writing (Taylor 2001; Sassoon 2003). Consideration of the angle of the paper and the student’s grip on the pen also ensures the student can write comfortably. Paper which is angled slightly allows for a natural writing position. Right-handed students should work with the paper slanting leftwards. For left handed students, the paper should slant in the opposite direction (Arter, McCall et al. 1996). A system for teaching handwriting to visually impaired students would need to consider the possibility of angling of the writing area. The way in which a student holds the writing implement is important to ensure they can comfortably write and easily produce letters. The “tripod” grip has been a commonly taught holding technique (Taylor 2001; Sassoon 2003). This grip can be developed from three fingers rigidly pressing against the implement into a more fluid hold with the pen held by the thumb and forefinger (Taylor 2001).

Lined paper can be used to provide a spatial reference while students learn the height and relative vertical position of letters. This also helps the student understand that some parts of letters hang below the baseline. It can be demonstrated that some parts of most lowercase letters are uniform height and that some strokes, called ascenders, rise above this height to the top line (Taylor 2001). A single baseline, double lines or four lines are all possible tools to help the students master these concepts (Sassoon 2003). Figure 2 shows lines and the spatial aspects of letters that they demonstrate. When teaching handwriting to visually impaired students, the same concepts need to be communicated non-visually. A suitable non-visual equivalent of lined paper could be used to demonstrate these spatial ideas.

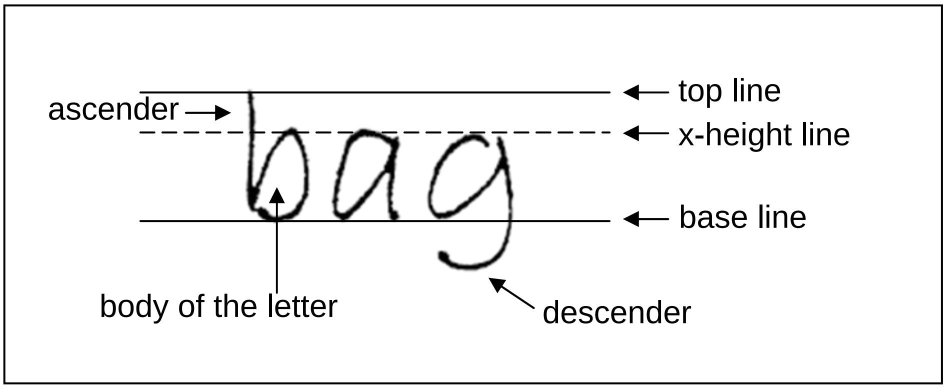


Figure 2 Spatial features of letters. Adapted from Taylor (2001).

When a teacher explains a concept, verbal instructions are often used. During the early stages of learning to write, spatial concepts may be frequently mentioned. An example is the concept of one letter being “after” another, or mention of the “top” or “bottom” of a letter. Depending on a student’s level of understanding, it may be necessary to work through these concepts with the student to ensure that he or she understands their meaning (Taylor 2001). This should occur early in the learning process when teaching visually impaired students handwriting.

Sometimes letter shapes can be explained by comparing them to real-world objects. For example, the shape of the "hump" of the letter *n* could be explained by comparing it to a mountain. Teachers should be aware that using these verbal cues with blind people requires careful thought, because a blind person may be inclined to draw a three dimensional object differently to a sighted person. A study about how blind people draw (Kurze 1996) reveals a number of ways in which blind users translate three dimensional objects into two dimensional pictures. Some participants drew three dimensional objects as if the surfaces were all folded out. Others drew objects as if the object was made of rubber and had been pushed down until it was flat. Still other drawings produced by participants pictured a section view of the object. These kinds of three dimensional to two dimensional mappings may not be intuitive to the teacher. Using three dimensional objects in verbal explanation could thus cause confusion.

In the earlier stages of learning to write, repeating patterns across a page can be a useful activity for developing the ability to form letter shapes (Taylor 2001; Sassoon 2003). For example, by doing a zig-zag pattern across the page, a student could gain confidence in forming shapes which can be used to form the letters *v* and *w* (Taylor 2001). These patterns could be used as a teaching tool for visually impaired students.

Letters can be characterised by the types of movement used to create them. When teaching the entire English alphabet, it has been suggested that letters involving similar sorts of shapes be taught together (Taylor 2001; Sassoon 2003). Letters can be classified as those consisting of straight line strokes, oval shapes, humps and shapes resembling a cup or zigzags (Taylor 2001).

Moving from printing single letters to joining the letters cursively requires significant learning. One approach is to add an extra stroke which flicks off the end of a letter, in preparation for joining the letter to the next. For certain letters, these "exit strokes" can be taught while teaching individual letters (Taylor 2001). It has been suggested that cursive writing could be particularly useful for visually impaired people as the vast majority of letters are formed starting at the baseline. This provides a spatial consistency and can sometimes allow the user to move through an entire word by depending on kinaesthetic feedback (Arter, McCall et al. 1996).

2.2 McSig 1.0

McSig 1.0 (Plimmer, Crossan et al. 2008) is a teaching and learning environment which was developed for teaching handwriting to visually impaired students. The work in the current project builds upon previous work carried out in the development of McSig 1.0 and its initial evaluation (Plimmer, Crossan et al. 2008).

McSig 1.0 is a multimodal system which used kinaesthetic, tactile and sound modalities to provide feedback to students. The system was designed for the teacher and student to use together. Figure 3 shows a teacher and student using the system. The teacher uses a Tablet PC and the student holds a pen which is attached to a mechanical arm on the PHANTOM haptic device. As the teacher forms a letter shape on a Tablet PC, the student experiences parallel feedback in all of these modalities.

Figure 3 A teacher and student using the McSig 1.0 system.

As the teacher's stylus moves over the surface of the Tablet PC, the coordinates of this movement are collected, and are used to move the end effector of the haptic device through the same trajectory in real time. The student's hand is guided around the path of the letter shape by the moving haptic device.

A continuously-playing sound tone is altered to express the movement of the student's pen. As the pen moves in the y axis, the pitch of the tone changes. As the pen moves in the x axis, a stereo panning effect occurs between the two speakers playing the tone. A distinctive sound is also played at the start and end of each stroke. Such sounds are known as "earcons".

The student's pen moves over a tactile writing surface. This consists of a plastic tactile sheet resting on top of a rubber surface known as a Dutch drawing board. Figure 4 shows a tactile sheet being attached to the drawing board. As the tip of the student's pen moves over the plastic tactile sheet, the sheet is scored, leaving a tactile ridge that the student can feel with their non-dominant hand. The teacher can verbally provide information about the letter shape being formed to assist the learning.

Figure 4 A plastic tactile sheet is attached to the Dutch drawing board.

The teacher can switch between two modes by means of a software GUI. In "teaching" mode (originally named "Playback" mode), the student is guided through letter shapes by a teacher. In the free drawing ("freedraw") mode, the student is able to attempt forming letters or a signature independently. The student can move the pen freely within the constraints of a rectangular working area. The student presses a button on the side of the PHANTOM pen to cause ink to appear on the teacher's display. The option is available to provide speech feedback to the student upon the completion of a letter. Once recognised, the letter is read aloud using synthesised speech.

The software in McSig 1.0 which controls the haptic device draws on the approach that was taken by Amirabdollahian et al. (2002) to create a haptic guidance system for stroke rehabilitation. This approach is used in conjunction with a PID Controller algorithm (Astrom and Hagglund 1995). This algorithm dynamically alters the forces applied by the device in order to move the user's hand along the trajectory smoothly. A library which had been created to enable the haptic device to move its end effector through trajectories (Crossan, Williamson et al. 2006) was used in the development of McSig 1.0.

A stencil mode, in which the student's hand is restricted to recorded trajectories, was trialled. This mode was considered unsatisfactory because of the lack of tactile feedback for the non-dominant hand to feel.

2.3 Non-Visual Modalities

To teach handwriting to visually impaired students, we must use non-visual modalities effectively. In the kinaesthetic modality, haptic guidance and constraint can be used to develop motor skills. The sound modality provides the opportunity to encode spatial information, or give symbolic signals to a student. The important tactile modality can be used to provide an awareness of the shapes of letters and strokes. Below we explore techniques that have been used with these modalities and relate them to the McSig system.

2.3.1 Kinaesthetic Modality

In order to learn handwriting, a student must successfully master the motor skills required to move the pen to generate letter shapes. Two significant approaches have been used to train users in motor skills. These are haptic guidance and haptic constraint. Work has been carried out in training handwriting or similar motor skills.

2.3.1.1 Guidance

Haptic guidance involves pulling the user's hand or arm around a trajectory. This has been used to teach motion to users. Haptic guidance has been applied in stroke rehabilitation, to teach Japanese and Chinese characters and to teach complex three dimensional motions.

A simple form of haptic guidance is a teacher guiding a student through a motion by placing their hand over the student's hand. This is less than desirable for demonstrating the correct force involved (Henmi and Yoshikawa 1998; Teo, Burdet et al. 2002). The advantage of the McSig 1.0 system is that more accurate guidance can be provided.

Haptic guidance can be used to guide a person's hand or arm through a trajectory as the user remains passive. One study used a robot arm to assist in rehabilitation of arm movements for stroke patients (Amirabdollahian, Loureiro et al. 2002). Reaching through a curved trajectory in order to retrieve an object from a shelf was a target skill to learn. A "Passive" mode was provided, where the user's arm is moved through a trajectory without any need for the person to apply effort. No evaluation was carried out on the success of this approach. This is equivalent to the teaching mode in McSig 1.0.

Recording a movement and then replaying it at a later time is one approach to motor skill training. One such system was used to teach Japanese calligraphy (Henmi and Yoshikawa 1998). A skilled teacher records the movements required to form a character. The student holds a physical rod which represents a calligraphy brush. The rod is moved through the teacher's recorded motion. An initial evaluation suggested that the system could help to teach the correct formation of a character, however the results were not conclusive. The same approach has been used to teach Chinese characters (Teo, Burdet et al. 2002). This system appeared to be effective for teaching users how to write Chinese characters. Neither of these systems were specifically designed for use with visually impaired people. It was noted in the McSig 1.0 study that it would be difficult for visually impaired students to control a system where recorded trajectories are replayed. While using McSig 1.0, both of the student's hands are in use. Voice commands could be used to control the system but the recognition would need to be very robust (Plimmer, Crossan et al. 2008). McSig 1.0 uses a real-time collaborative approach. The teacher and student work together. Since the guidance is given in real-time, the teacher can slow down for difficult parts of a letter. The teacher can also repeat parts of the letter that need emphasis.

Mullins, Mawson et al. (2005) developed a system to aid stroke patients in rehabilitating their handwriting skills. The system displays text using a font which resembles handwriting. A PHANTOM Omni haptic device is used to guide the user's hand through the motion of letter formation at a fixed speed. From the evaluation it is unclear whether the system is successful at improving motor skills for handwriting. McSig 1.0 takes the ideas used in this system further by allowing a teacher to demonstrate free-flowing, cursive handwriting, varying the speed in a natural manner. Because McSig 1.0 is designed for use with visually impaired students, the haptic guidance needs to be integrated with feedback in other non-visual modalities.

2.3.1.2 Constraint

With haptic constraint, the user may be free to explore by moving part of the haptic device with their hand. Certain limits are put on the movement, such as a virtual boundary past which the device will not move.

Haptic constraint technology has been used to allow blind users to explore graphical information (Yu and Brewster 2003). Line graphs and bar graphs were made available to blind users using a haptic device. The user holds the end effector of a PHANTOM device and experiences forces as it is moved over parts of virtual objects making up the graphs. The authors note a limitation of this system. The haptic device only gives haptic feedback on a particular point. This means that the user needs to explore a lot before beginning to understand a region of the graph. A similar constraint-based approach may be useful for a student exploring a letter shape but it does not demonstrate the motor skills required to form the letters.

Virtual stencils have also been used. In a system for teaching Chinese calligraphy (Teo, Burdet et al. 2002), there is a mode which allows the user to move the pen at variable speeds around a path. The pen is constrained to within the shape of the strokes recorded by the teacher. This system differs from a system for visually impaired people because significant visual feedback is provided. When designing a virtual stencil system for visually impaired students, the tactile modality needs consideration. The stencil mode provided in McSig 1.0 was unsuccessful because there is no tactile feedback available for the student's non-dominant hand to feel (Plimmer, Crossan et al. 2008).

A virtual surface can be provided for the user. This could be dynamically altered to allow a user to experience letter shapes. The system created by Rassmus-Gröhn, Magnusson et al. (2006) allows visually impaired users to freely draw pictures on a virtual writing surface, using the Sensable Technologies PHANTOM haptic device. The drawings are stored as grayscale images, where a black denotes a positive relief, and white denotes a negative relief. The user is able to move the haptic device around the virtual writing surface to experience the changes in relief. A qualitative evaluation with visually impaired students showed that they were able to easily feel lines using the device. Two other systems make interesting use of a virtual surface. The system for teaching Chinese characters (Teo, Burdet et al. 2002) re-creates the feeling of a calligraphy brush. The haptic device moves softly towards the virtual surface, as if pushing against brush fibres. The system used for teaching Japanese calligraphy (Henmi and Yoshikawa 1998) gives a natural feeling of friction on a virtual surface. Neither of these two systems was evaluated with visually impaired people. In McSig 1.0, a physical tactile surface is used. This provides the student with vital tactile feedback that can be felt with the non-dominant hand.

The system for rehabilitation of arm movements (Amirabdollahian, Loureiro et al. 2002) has a mode called "Active" mode. During this mode, the user is free to attempt to move their arm through a predefined trajectory. When the user's arm movement is in error, then assistance is provided by the robot arm. The success of this approach was not evaluated. This kind of approach has not been explored with McSig 1.0. With McSig 1.0, the student is either guided around the letter shape, or they attempt the letter independently.

2.3.2 Sound Modality

There are a number of approaches that have been used to present spatial information using the sound modality. Voice recordings, synthesized speech, earcons, three dimensional sound and sonification of spatial data can all be used as output sound to convey information. Users can actively navigate data to obtain audio feedback, or are passive and are presented with the feedback.

Audio recordings can be mapped to spatial locations. The Talking Tactile Tablet (Landua and Wells 2003) plays audio when areas of a tactile sheet are touched. Initial testing suggested that users rated a tactile and audio system as easier to use and more enjoyable than a system with tactile feedback alone. The results published were not conclusive because the authors acknowledge that the testing methodology needed improvement. In McSig 1.0, recorded audio is not used. The verbal instructions provided by the teacher during lessons are an important part of the student's learning.

Synthesised speech can be used to convey information. This offers flexibility because a string of text, which is easy to modify, can be read aloud. With TDraw (Kurze 1996), the user can touch lines and shapes on a tactile drawing with a pen in order to hear the corresponding verbal information played as synthesized speech. No evaluation was carried out on the benefit of providing this kind of feedback. Another system (Yu and Brewster 2003) allowed partially sighted and blind users to hear data values from within graphs in the form of synthesised speech. The study found that users answered questions about the graphs more accurately when synthesised speech and pitch feedback were combined with raised tactile graphs. Synthesised speech was seen to play a large part in this success because numerical values read aloud to the user are clear and unambiguous. In McSig 1.0, the student's attempts at letters can be read aloud using synthesised speech. Incorrect recognition results were discouraging for users in an initial McSig 1.0 usability test, so the teacher was given the option to disable it (Plimmer, Crossan et al. 2008).

Earcons are distinctive musical sounds. These can be used as an abstract marker to indicate an event. Earcons have been shown to be a successful tool for conveying information (Brewster, Wright et al. 1993). Hoggan and Brewster (2007) developed a set of cross-modal icons for mobile devices. Sound icons were used to indicate the type, urgency and sender type for a message recieved on a mobile phone. The type of message was indicated by playing musical notes in three different rhythms. Vibraphone and piano sounds were used to create a sense of roughness and smoothness of the sound, respectively. A rough sound corresponds to an urgent message. Earcons are used to indicate the start and end of a stroke in McSig 1.0.

Sonification is the field of study involving encoding data as sound. Pitch, pan and timbre are examples of attributes of a sound that could be altered to express information. To express information effectively, one must consider the resolution of the change. The mappings between data and sound must also be carefully considered. The iSonic system (Zhao, Plaisant et al. 2008) is used to display spatial data, such as maps, using sound. The user can navigate around a map using a touchpad or the buttons of a conventional keyboard. The keyboard can be used to indicate movement in a direction or to point at an absolute position. Five discrete pitches of a violin sound are used to indicate which range a numeric value falls within. Stereo pan is used to indicate movement between the left and right. Case studies with seven visually impaired people found pitch to be a succesful and engaging way to convey numeric data. The study found that users tended not to focus on using the stereo pan feedback. Another system involving sonification was developed by Yu and Brewster (2003). The system allows users to access information from graphs and tables using a haptic device. The user can retrieve information about the values of data in the form of musical notes. The pitch of the note corresponds to the magnitude of a value. McSig 1.0 uses pitch and pan to convey the movement of the pen in two dimensional space. In teaching mode, the student is passive and is presented with the sound output. In freedraw mode they actively move the pen, similar to the navigation used in the iSonic system.

Three dimensional sound is another way that information could be conveyed. Hoggan and Brewster (2007) used three dimensional sounds to indicate the category of the sender of a message. The sounds were played three dimensionally by placing sound sources in three distinct locations. Zhao, Plaisant et al. (2008) make reference to the use of Head Related Transfer Functions (HRTF). This technique allows properties of a sound to be altered to cause a sound heard through headphones to be percieved as originating from within a three dimensional space. McSig 1.0 uses three dimensional sound for the stereo pan effect. The physical placement of the two speakers allows stereo pan to be heard.

2.3.3 Tactile Modality

There are a range of techniques that have been used to display information in a tactile form for both visually impaired and sighted users. Physical objects can be manipulated to create tactile shapes. Paper or plastic can be given raised sections which can be touched. Pin arrays can be used to display a three dimensional shape.

It has been noted that traditional tactile learning tools such as plastic letters or stencils can be used to give a student awareness of letter shapes (Plimmer, Crossan et al. 2008). Pipe cleaners are another possible tactile tool for explaining shapes. Flour or sand can also be used to allow students to scribe lines with a finger in a tactile manner (Taylor 2001). In McSig 1.0, the primary tactile feedback is through the plastic tactile sheet. Tactile aids could be used in combination with McSig 2.0.

Raised paper or plastic diagrams can be used to display information for visually impaired students. A problem with this is that they are usually static and can not be configured. Plastic sheets can be thermally moulded to produce raised or textured areas. This has been carried out for maps and shapes in order to teach visually impaired students (Wells 1986). Using a key in Braille allows the user to associate sections of a map with textual information. The Talking Tactile Tablet (Landua and Wells 2003) uses a touch sensitive tablet, overlaid with paper which has raised regions. The authors do not evaluate the effectiveness of the tactile feedback, as it seems to be assumed to be of educational value. The raised paper can be touched by a user and plays audio upon various parts being touched. Although the mapping of areas of the tactile surface to audio is configurable, custom raised paper sheets must be made for each new application. For teaching letter shapes in combination with motor skills in real time, we require more dynamic tactile feedback.

“TDraw” (Kurze 1996) is an interactive drawing system for visually impaired people. The system allows users to create drawings upon swell paper using a thermal pen. A digitiser beneath the swell paper is used to obtain the position of the pen. The user is able to feel the lines that have been drawn on the swell paper. The success of this technique was not specifically evaluated. The study noted that the ability to erase or alter tactile drawings would be desirable features for future tactile technologies. A tactile surface is used in McSig 1.0. The advantage of the plastic sheet used in McSig 1.0 is that no special pen is required.

Pin arrays allow information to be displayed dynamically, but the resolution of these can be limited. Wall and Brewster (2006) presented a system to help visually impaired people gain access to information in bar graphs. The user uses one hand to move a stylus around a graphics tablet. The fingers of the other hand can touch two small tactile pin arrays which are incorporated into a mouse. As the user moves the stylus over the tablet, the pixels close to the corresponding mouse cursor position are monitored. Pixels which are darker than a specified threshold value cause the pins to be raised. As the cursor moves over features of a graph, such as a line forming the edge of a bar in a bar graph, tactile feedback is provided for the fingers touching the pin arrays. Participants in this study found that the low resolution of the pin arrays was problematic. Although pin arrays merit further investigation, pin arrays currently appear unsuitable for use within McSig 2.0.

2.4 Summary

There are a number of helpful techniques that can be used to communicate in the kinaesthetic, sound and tactile modalities. Some of the non-visual techniques that have been discussed are used in McSig 1.0. Building on the base of McSig 1.0, the system will be enhanced using a number of techniques. Some of the techniques that have been discussed will be used in the upgrade to McSig 2.0 and others will be discarded.

The literature on teaching children to write highlights that non-visual lines should be considered for McSig 2.0. Angling the writing area also requires consideration.

Furthermore, we should ensure that the student can hold and use the pen ergonomically.

In the kinaesthetic modality, the McSig 1.0 system focuses on using the haptic guidance approach. In the teaching mode, the student's hand is guided around the letter shape without the student needing to apply effort. Rather than using a record and replay approach, this is carried out in a real time collaborative manner. The teacher is able to demonstrate free-flowing handwriting in real time. The constraint-based stencil approach used in McSig 1.0 will not pursued in McSig 2.0 because of a lack of tactile feedback for the non-dominant hand.

In the sound modality earcons, pitch and stereo pan are used. In McSig 1.0, earcons are used to indicate the start and end of a pen stroke. Pitch and pan are used to express the movement of the pen. The pitch will continue to be used in the y axis and stereo pan in the x axis. Attention will need to be given to the resolution of change of the stereo pan. Stereo pan is a form of three dimensional sound, because the two speakers are placed in different locations on the desk.

In McSig 2.0, the important tactile feedback will continue to be primarily provided using the plastic tactile sheets. Tactile aids such as pipe cleaners could also be used during the longitudinal study. Pin arrays currently appear unsuitable for use in McSig 2.0.

Chapter 3

System Upgrade

A system upgrade to McSig 1.0 was carried out with the objective of more fully supporting the task of learning a signature for visually impaired students. The upgraded version of McSig 1.0 is called McSig 2.0. The upgrade improves the core feedback provided for the student, implements handwriting teaching concepts and adds teacher tools to make teaching sessions run smoothly.

3.1 Methodology

The requirements for the upgrade come from four sources. First, the McSig 1.0 study (Plimmer, Crossan et al. 2008) identified some clear usability problems with the system. Second, the literature on teaching children to write reveals a number of basic teaching techniques. Suitable non-visual equivalents can be implemented into McSig 2.0. Third, our own observations about the effectiveness of McSig 1.0 contribute to the requirements. Finally, changes are needed to prepare the system for the longitudinal study.

A participatory design and development approach (Dix, Finlay et al. 2004) was used to upgrade the system. This approach involves the end user in the design of the system. The user is not just observed or questioned, but plays an active role in contributing to the design decisions.

Informal evaluations were carried out with a visually impaired adult, “Sue”, who was one of the participants in the previous McSig 1.0 usability study (Plimmer, Crossan et al. 2008). The target user group for McSig is congenitally blind children and the previous study showed that congenitally blind people interact differently than those who have seen (Plimmer, Crossan et al. 2008). The extremely limited pool of visually impaired children makes it unfeasible to have child participants. From among those who participated in the previous study, Sue was the closest match to the target user group because she is congenitally blind.

On three occasions during the enhancement implementations Sue helped to evaluate different design options relating to the blind user's interaction. The design process was iterative. Several implementation options were explored where necessary. The most promising option was selected. For example, while refining the sound pan feedback, Sue trialled the use of headphones and the various stereo pan options in order to refine the interaction experience for a blind user.

Evaluation of the system is carried out using the Cognitive Dimensions framework (Green and Petre 1996). The framework is described in depth in Section 4.1. A summary of the findings of the Cognitive Dimensions evaluation is presented in Section 4.2. Conclusions are drawn in Section 4.3.

3.2 Requirements

The following problems with McSig 1.0 need to be resolved in McSig 2.0:

- Button-pressing is needed for the student to write in freedraw mode in McSig 1.0 (Plimmer, Crossan et al. 2008).
- The PHANTOM pen is bulky and difficult to hold in McSig 1.0 (Plimmer, Crossan et al. 2008).
- Lines are not available in McSig 1.0, as they are when students learn to write with lined paper.
- Angling the writing area has not been incorporated into McSig 1.0 for ergonomics.
- Inaccuracy in the trajectory playback arises from tilting of the student's pen.
- Sudden jerking movements can occur when the student's pen is moved to the beginning of a stroke.
- Screenshots are difficult to capture without interrupting the flow of a lesson.

- Keyboard shortcuts should be provided for the teacher.

3.3 Button-Press Removal

During the mode where the student uses the PHANTOM pen to write, the student is required to push a button on the side of the pen. When the student is holding down the button, ink is shown on the teacher's display. Having to hold down a button can distract from the student's primary task, namely, moving the pen around the intended motion. It may also introduce forces which interfere with the writing motion. The requirement to hold the button down during the motion may also prevent the student from maintaining a conventional and ergonomic grip of the pen.

The button-press problem was addressed by sensing the height of the pen tip. The ink can be displayed on the teacher's display when the student's pen tip is moving over the writing surface. The height of the pen tip can not be obtained from the haptic device. The z coordinate that can be obtained from the haptic device is a point part way up the pen (the "Gimbal Point" in Figure 5). To calculate height of the pen tip, an offset was added to the z coordinate given by the device. Using a simplified model of the pen and gimbal (shown in Figure 5), trigonometry can be used to calculate the offset. The offset is marked as "y" in Figure 5.

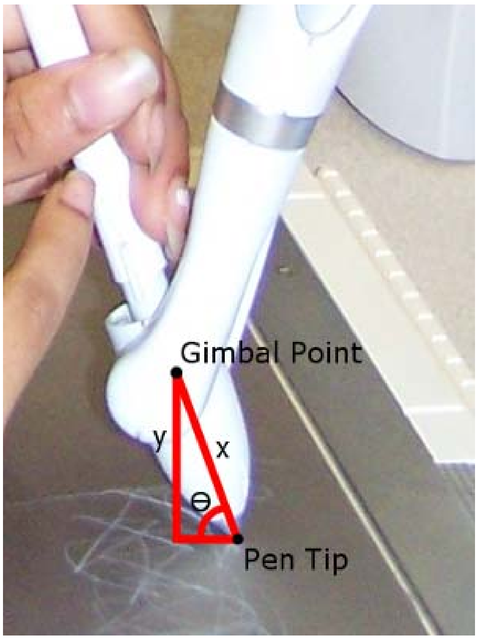


Figure 5 Trigonometry can be used to calculate the pen tip height.

As part of calculating the offset (“y”), the value marked “x” is used. This is a constant value, determined by the physical distance from the gimbal point to the pen tip. The tilt of the pen with respect to the writing surface is also needed. This is marked as □ in Figure 5. The angle of the pen available from the PHANTOM device is given with respect to the shin of the mechanical arm (see Figure 6), which is given with respect to the “thigh”. The combination of all of these angles must be considered to get the angle of the pen with respect to the writing surface. The gimbal can also rotate about the shin. Because of the complexity of an implementation considering this rotation, we used the simplified model (shown in Figure 5).

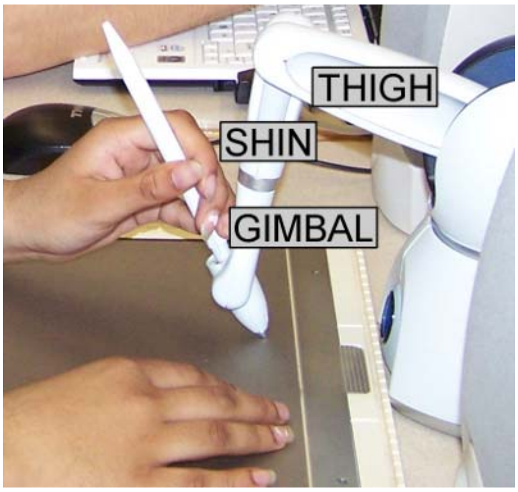


Figure 6 The “shin”, “thigh” and “gimbal” of the PHANTOM’s mechanical arm.

Once the pen tip height is calculated, we can check whether the pen tip is within a threshold distance from the writing surface. Once it is close enough, ink is displayed on the teacher’s screen and the sound feedback begins for the student.

By sensing the height of the pen-tip, we eliminate the need for the student to hold down a button on the pen to switch into an inking mode. A further benefit is that the student will learn that they must only touch the pen on the writing surface when they intend to make a mark on the page. This interaction more closely replicates the task of using pen and paper.

3.4 Replacing the PHANTOM Pen Shaft

The diameter of the pen included with the device had a relatively large diameter, making it difficult to hold and noticeably different to handle in comparison to a standard ballpoint pen.

The thick standard PHANTOM Omni pen was replaced by a thinner pen shaft. The standard pen was detachable, and a thinner plastic shaft was attached as a substitute. Sue found this pen much easier to hold.

Figure 7 The McSig 1.0 pen shaft (left) and the thinner replacement in McSig 2.0 (right).

3.5 Non-Visual Lines

No equivalent to lined paper was used in McSig 1.0, making it difficult for students to grasp the important spatial concepts that lines reinforce. A suitable non-visual equivalent of lines on paper is needed.

Several options were considered. One option is to alter the character of sound that is playing according to the position of the pen in the y axis. As the pen moves past a certain y axis position, a change in the character of the sound feedback could indicate that a line is located at that position. A second option to consider is the use of a virtual haptic ridge. As the student's pen tip moves over the location of the line on the writing surface the z coordinate could be altered to lift the pen off the page slightly, causing a bump sensation. Both of these options have the significant disadvantage that no tactile feedback is available for the student to touch with their non-dominant hand. This is considered an important part of the interaction (Plimmer, Crossan et al. 2008).

Physical tactile lines are able to be felt by the user, and a number of options exist for implementing these. A calibration step is required for some options, as the teacher needs a view of the lines on their writing area which corresponds to the placement of the lines on the student's writing area. Plastic sheets could be thermally pressed to form physical ridges, and placed on the writing surface. Because they could be placed in predefined positions, no calibration with the teacher's view would be necessary. A problem is that they are static and unable to be configured. Another option is that the teacher could rule a straight line while in teacher mode, causing a line to be drawn on the tactile sheet of plastic. This would require no further calibration or equipment, but it could be time consuming and also lacks flexibility. This was trialled with Sue and was found to be difficult to carry out accurately and quickly. Nylon threads placed beneath the plastic tactile sheet are a promising alternative, but these easily slip out of position beneath the plastic sheet when touched.

Rubber bands placed beneath the tactile sheet were chosen as suitable tactile lines. A rubber band is shown, stretched around the drawing board, in Figure 8. The plastic tactile sheet is attached over the top of the rubber band. Rubber bands of two different thicknesses can be used in order to show lines of differing importance. For example, if three lines were used, the middle line could be thinner. The rubber bands were found to be effective with Sue.

When using rubber bands, a calibration step is required, however this allows the flexibility to add, remove and position lines as necessary for teaching sessions. Because lines are always parallel to the x axis of the writing plane, only the position of the line in the y axis needs to be considered during calibration. The student's pen is placed with the tip on the rubber band (as shown in Figure 8) and the teacher pushes an "Add Line" button on the teacher view software interface.

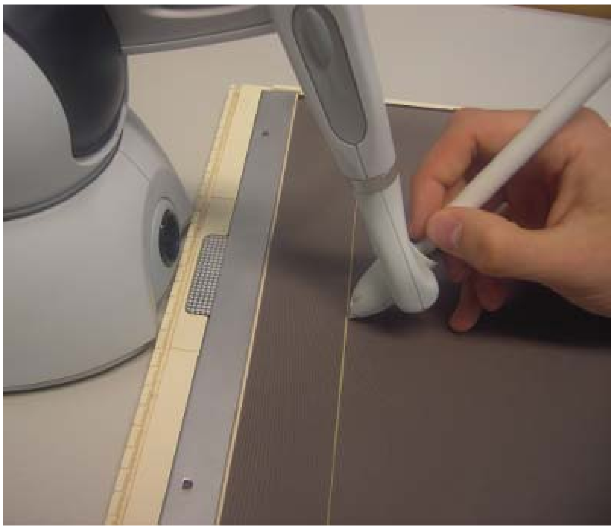


Figure 8 Calibration of lines is done by holding the pen tip on the rubber band.

This causes a line to appear on the teacher's writing area for the duration of the teaching session. Two lines are have been added in Figure 9. The teacher can add multiple lines and remove lines using an undo button.

Figure 9 The teacher view of McSig 2.0, showing lines that are calibrated to the position of the student's tactile lines.

3.6 Angling the Writing Area

The angling of the paper leftwards or rightwards is an important ergonomic consideration when writing with pen and paper. McSig 1.0 had no way of replicating the idea of slanting a sheet of paper.

A cardboard template (shown in Figure 10) was devised to keep the writing area on an angle during teaching sessions. This has outlines that show where to place the drawing board and the haptic device.

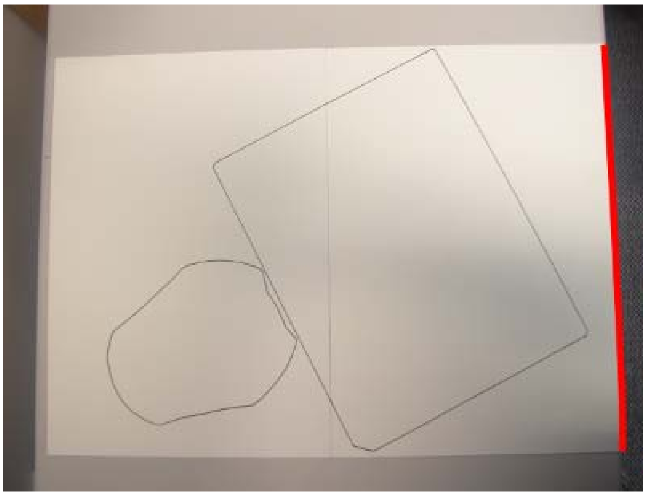


Figure 10 A cardboard template used to keep the writing area on an angle. The template lines up along the desk edge, indicated in red.

Sue indicated that turning the writing area on an angle could potentially disorientate a student. However, she suggested that it may be of use, particularly for long teaching sessions. Discomfort could be prevented by keeping the ergonomic writing posture that is encouraged by angling the writing area.

Figure 11 A cardboard template facilitates a more ergonomic writing posture.

3.7 Pen Tip Position Correction

Tilting of the student's pen causes inaccuracy in the trajectory playback. In McSig 1.0, the point that is moved around the trajectory is part way up the pen, where the pen is attached to the mechanical arm. The pen is able to tilt as it rotates about an axis (shown in Figure 12). Below the attachment point, the pen tip can deviate from the trajectory. As a result, the teacher may scribe a straight line, and because the student is tilting their pen during the motion, the student's pen tip will scribe a bent or bendy line on the tactile surface.

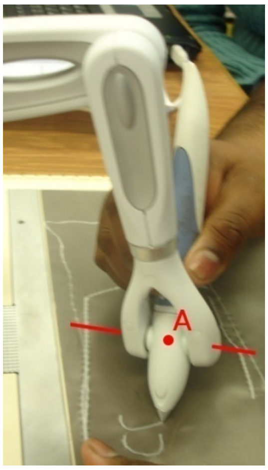


Figure 12 Point A is moved about the trajectory and the student can tilt the pen about the axis indicated.

There are two approaches that could be used to correct the position of the pen tip during trajectory playback. First, the pen could be held at a fixed angle. This makes the pen difficult to hold and constrains the user more than we would like, as the student is not free to tilt the pen. The alternative is to indirectly alter the position of the pen tip by considering the angle of the pen. The angle of the pen can be obtained from the PHANTOM hardware, although it can not be mechanically altered. We can only control the position of the gimbal point (Point A in Figure 12), and not the pen tip. With this information we could dynamically calculate the position of the pen tip in relation to the gimbal point using trigonometry, and adjust the position of the gimbal point to give a new resulting pen tip position. Similar to the pen-tip height sensing in Section 3.3, the calculation of this offset is complicated by the fact that the gimbal that holds the pen can also rotate.

Due to the complexity of calculating comprehensive correction accurately, a basic version of this correction has been implemented. We had observed that the angle of the pen varied the most along the y axis, as the user tends to tilt the pen with the pen facing forwards, approximately parallel to the y axis. By storing the original angle, the difference between the original and current angle can be calculated. This value can be used to calculate the distance that the pen tip needs to be offset. When this simple offset is applied the effect on the trajectory of the pen is sufficient for normal use.

3.8 Indicating the Student's Pen Position to the Teacher

Sudden jerking movements can occur when the student's pen is moved to the start point of a stroke. When the teacher's stylus first contacts the tablet screen, the PHANTOM pen moves to the corresponding position within the student's writing area. The sudden jerking movement occurs if this initial point is a significant distance from the previous position of the student's pen. This could potentially be uncomfortable for the student or cause disorientation.

Visual feedback was added to show the teacher the current position of the student's pen within the writing area. A moving blue dot was added to the teacher's display to indicate the current position of the student's pen. This can be seen in Figure 13. The teacher aims to make first contact with the tablet close to the dot so that the student's pen will not have to move far to begin following the teacher's pen. By polling every 10ms, the position of the student's pen is read from the haptic device and displayed on the teachers' view.

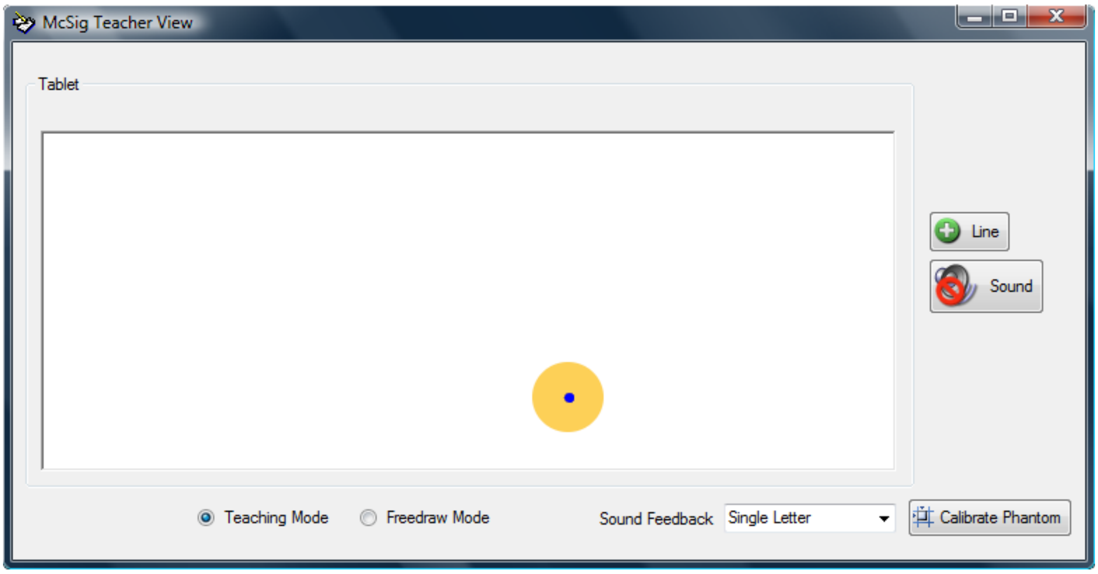


Figure 13 The blue dot (highlighted with orange here for clarity) shows the position of the student's pen to the teacher.

From the PHANTOM device, x, y and z coordinates were obtained. These coordinates are with respect to the vertical plane facing the device. These were translated appropriately to get the x and y coordinates for the writing surface plane. Adjustments then needed to be made to the coordinates. The PHANTOM coordinate system places the origin in the centre of the dimension, with positive and negative values proceeding from this point. To display this position on the teacher's software, the coordinates need to be adjusted to fit within a rectangle, with the origin at the top left corner. Once scaled to fit the teacher's viewing area, the dot can be rendered in the correct position. So that the primary task of the teacher is not interrupted, the dot disappears when the teacher is drawing an ink stroke. CursorDown and Stroke events represent the time when the stylus first touches the tablet and leaves the tablet, respectively. These events are used to toggle the visibility of the trailing dot.

3.9 Improving Stereo Pan Feedback

Changes in stereo pan for movement of the pen in the x axis are sometimes difficult to hear. A large change in the position of the pen is needed to create any discernable change in stereo pan. This means that no useful feedback is provided for small movements of the pen. In McSig 1.0, the pan changes according to the position of the pen with respect to the drawing canvas. The pen would need to be moved all the way from the left of the canvas to the right of the canvas in order to move the stereo pan through its full range. A small letter which is carried out near the left of the drawing space would result in pan feedback which remains mostly at the left, with little discernable change.

There are conflicting challenges to provide feedback with stereo panning in the x dimension. First, small changes in the stereo pan are difficult to discern. We should seek to provide the largest possible change in panning. Yet, there is a large range in the width of strokes that we would like to provide feedback for. Useful feedback must be produced for small thin letters, but also for large wide signatures.

In addition, positions of the speakers on the desk are variables that affect how panning is heard. If the two speakers are too close together the sound may appear to be coming from a single source, even when significant panning occurs. During any teaching session, the speakers need to be placed a suitable distance apart. We asked Sue to try using headphones instead of standing speakers, to see if this could make it easier to hear a change in pan. However, she found the headphones less satisfactory for discerning stereo pan. Headphones also prevented her from hearing verbal instructions from the teacher. Although headphones may potentially prove useful for some, it appeared that a more serious alteration of the sonic feedback was required.

To maximise the change in stereo pan, different panning feedback is provided for single letters and entire signatures (see Table 1). By providing a single letter mode, the sound can be made to pan sharply to the left or to the right even when a small letter is drawn. The pan is also made dynamic, occurring with respect to the starting position of the pen, rather than with respect to the drawing canvas. Visual feedback for the teacher is vital here, so the teacher is provided with a visualisation of the panning on their drawing area. Colour shading shows where the panning reaches its left and right extremes, allowing the teacher to draw the letter at a size that would produce the largest possible change in stereo pan for the duration of the stroke. The visualisation is provided from when the stylus pen touches the screen until it is lifted off. When a stroke begins the sound plays at a centred pan position, and panning moves towards the left and right relative to this starting point. Many letters in the English alphabet fall entirely to the left or to the right of their starting point, and this idea can be reinforced by causing panning to occur relative to the starting point of a letter.

When writing entire signatures, it is necessary to change the stereo panning to the entire width of the signature, so that meaningful feedback is given to the student over the full range of movement in the x axis. A signature will usually be carried out with one primary stroke, with a width almost as wide as the writing area. A signature mode is provided which provides a change of pan for a greater width of the writing area. At the starting point of the stroke the stereo pan will be near the left extremity. This starting point is slightly to the right of the left extremity, to allow change in stereo pan to occur even when the signature stroke moves slightly to the left before moving predominantly towards the right.

The teacher can customise the signature and single letter modes to produce a range of differing behaviours. Customisation is carried out by selecting either the “Custom Single Letter” or “Custom Signature” mode. The teacher is then prompted to draw an example letter or signature on the screen. The width of this example stroke is used to determine how wide to make the custom stereo feedback span. For example, in Table 1, the Custom Single Letter mode has been customised to give better feedback for smaller, thinner letters. Customisation of the modes can be carried out during teaching sessions when the lesson moves on to learning and repeating a new stroke with a considerably different width to previous strokes.

The two modes were tested with Sue. She considered that the single letter modes made it considerably easier to hear the change in stereo pan. Sue suggested that the same sound feedback be added in to the freedraw mode, in order to provide consistent feedback. This also allows students to compare the feedback received during the teaching and freedraw modes.

	Signature Mode	**Single Letter Mode**
Default		
Custom		

Table 1 The teacher can select suitable stereo panning behaviour. The solid grey regions show where the panning has reached its leftmost or rightmost extremity.

3.10 Screenshot Capture Tool

We planned to track students' progress by taking screen shots during lessons. We trialled this with Sue and found that we had difficulty collecting and organising screenshots of her attempts at letter shapes. It was difficult to capture, name and save the example quickly, while still keeping the flow of the lesson.

A custom screenshot tool was added into the teacher's software interface to avoid delays. On the first click of the screenshot button (shown in Figure 14), the teacher is prompted for the name of the student. The software then creates a folder, named with the student's name, the date and time. After this setup step, whenever the screenshot button is pressed, the software takes a screenshot of the writing area and automatically saves it as a .png file in the folder using the same naming convention. Any lines that have been added to the writing area are also included in the screenshot.

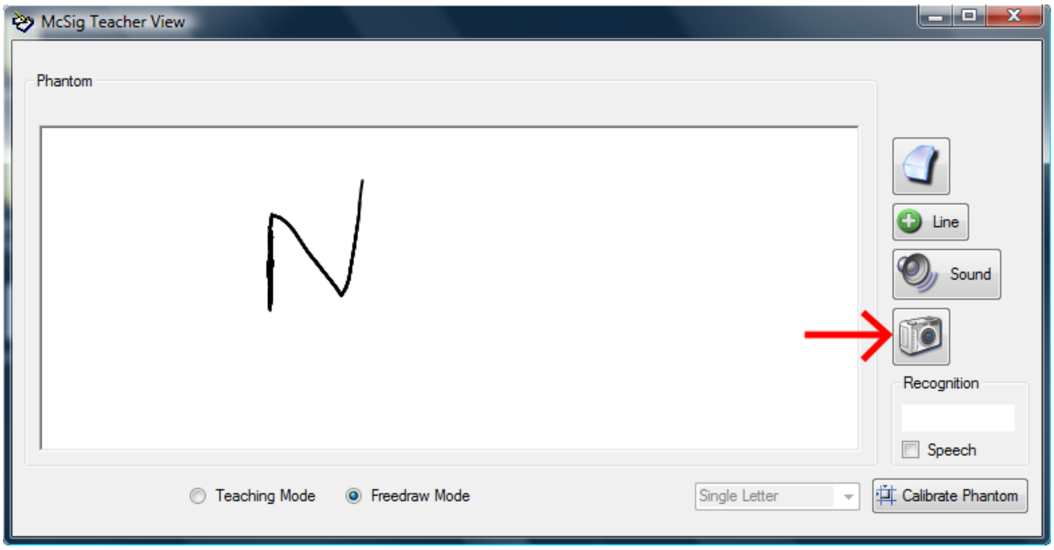


Figure 14 The teacher can click the screenshot button indicated to save a screenshot of the writing area.

3.11 Keyboard Shortcuts

Keyboard shortcuts were provided to enable the teacher to quickly carry out common tasks. Turning the sound on and off, switching between teaching and freedraw modes, and taking screenshots are high-frequency tasks which can be carried out more quickly using these shortcuts. The shortcuts are shown in Appendix 1, the McSig 2.0 Teacher View User Manual.

3.12 Scenarios of Use

3.12.1 Demonstrating a Small Letter

The teacher wishes to demonstrate the formation of a particularly small letter *e* several times and then allow the student to try. The teacher wishes to capture a screenshot of the student's attempt and then demonstrate the letter again. The letter *e* is smaller than the default size for the "Single Letter" stereo pan mode.

1. The teacher selects "Custom Single Letter" from the stereo pan options drop-down menu.
2. A message appears asking the teacher to draw a training stroke. The teacher scribes the letter *e* on the Tablet PC screen.
3. The teacher scribes the letter on the Tablet PC screen to demonstrate the letter to the student. As this is done, the student's hand is moved through the formation of the letter. The pitch of the sound increases and decreases as the pen moves upwards and downwards. The pan of the sound moves between the centre position and the far right.
4. The teacher demonstrates the letter a number of times until the student is confident to attempt it.
5. When the student decides that they are ready to attempt the letter, the teacher switches to freedraw mode.
6. The student moves the pen to attempt the letter. Similar sound feedback to that in teaching mode is experienced. Ink shows up on the teacher's display as the student moves their pen.
7. The teacher clicks the screenshot button to save a screenshot of the example.
8. To demonstrate the letter again, the teacher switches back to teaching mode.

3.12.2 Demonstrating a Signature on a Baseline

The teacher wishes to demonstrate a signature a number of times and then allow the student to attempt it. The default setting for the "Signature" panning mode is suitable.

1. The teacher puts a rubber band around the Dutch drawing board and attaches the tactile plastic sheet over the top.
2. To calibrate, the teacher or student holds the PHANTOM pen so that the pen tip touches the rubber band.
3. The teacher clicks the "Add Line" button on the software GUI or uses the Ctrl-L shortcut key. A line appears on the teacher's view.
4. The teacher scribes the signature on the Tablet PC screen. The pitch changes upwards and downwards as the pen moves upwards and downwards. The pan moves from left to right, beginning a small distance from the left.
5. When the student is ready, the teacher changes to freedraw mode.
6. The student attempts the signature. The student is given sound feedback similar to the feedback given in teaching mode. Ink shows up on the teacher's screen.

3.13 Summary

Changes carried out to the system can help teaching sessions run more smoothly, make the system easier for the student to interact with and improve the core feedback offered to the student regarding letter shapes. Techniques for teaching children handwriting are implemented non-visually.

The changes to the stereo pan are particularly important because they enable us to more effectively teach single letters. In McSig 1.0 inadequate feedback is provided for single letters, because many letters are too small to produce a change in stereo pan that can be heard. This means that sometimes information about the movement of the pen in the x dimension may not be communicated. McSig 2.0 makes it possible to provide meaningful feedback in the x axis for single letters.

The tilting of the PHANTOM pen about an axis causes problems. This aspect of the PHANTOM Omni hardware caused difficulty both in removing the button-press and in improving the trajectory playback accuracy.

Chapter 4

System Evaluation

4.1 Evaluation Framework

Because of the very small user population we could not consider a standard usability test. As an alternative we have taken a two-pronged approach. We have carried out participatory design (Dix, Finlay et al. 2004) with a visually impaired adult as described in Chapter 3 and have used the well known Cognitive Dimensions framework (Green and Petre 1996). This framework allows the developers of visual environments to use independent measures to discuss aspects of a system. In this section we examine McSig 2.0 in light of each of Green and Petre's dimensions, where necessary, adapting the visual criteria to the sound and tactile interface.

Green and Blackwell's tutorial on Cognitive Dimensions (Green and Blackwell 1998) says:

> *"Giving names to concepts (lexicalisation) is essential to serious thought and discussion. Once names are given, discussants do not have to explain each idea every time they use it; they can refer to the idea knowing that the other party will understand it. Paradigmatic examples help to make the concepts concrete. Comparisons of trade-off costs become easier. Above all, a checklist can be constructed, to make sure that an evaluative discussion has not overlooked important aspects."*

The framework proposes fourteen standard dimensions to examine such aspects as abstraction, mapping and dependencies; visibility, consistency and error-proneness. The set of Cognitive Dimensions is shown in Figure 15.

Abstraction types and availability of abstraction mechanisms
Hidden dependencies important links between entities are not visible
Premature commitment constraints on the order of doing things
Secondary notation extra information in means other than formal syntax
Viscosity resistance to change
Visibility ability to view components easily
Closeness of mapping closeness of representation to domain
Consistency similar semantics are expressed in similar syntactic forms
Diffuseness verbosity of language
Error-proneness notation invites mistakes
Hard mental operations high demand on cognitive resources
Progressive evaluation work-to-date can be checked at any time
Provisionality degree of commitment to actions or marks
Role-expressiveness the purpose of a component is readily inferred

Figure 15 The Cognitive Dimensions. From "Cognitive dimensions of information artefacts: a tutorial" (Green and Blackwell 1998)

The framework has broad application. Anything which is an "information artefact" (Green and Blackwell 1998) can be analysed using the dimensions. The Cognitive Dimensions tutorial explains: "Information artefacts are the tools we use to store, manipulate, and display information" (Green and Blackwell 1998). For each dimension the designer can consider aspects of the artefact. For example, in a word processor, if the user is "Manually changing US spelling to UK spelling throughout a long document" (Green and Blackwell 1998), a designer may observe that the cognitive dimension *viscosity* is apparent. The dimension *viscosity* encapsulates the idea of resistance to change. Use of the framework has been shown to be an effective way to review interactive design in a range of systems (Green and Petre 1996).

Discussion of a system in terms of the dimensions allows for discussion of the trade-offs between dimensions. For example, *viscosity* may be alleviated by adding *abstraction* mechanisms. For the word processor example mentioned above, this could involve adding a styles manager to manage styles. This would allow the language for spelling to be changed in many places at once by altering a style.

However, this may result in increased *premature commitment*, as the choice of styles earlier on in the editing process could make it easier or more difficult to change the language for spelling later on.

We conducted a full review of the McSig 2.0 system in terms of these dimensions. This allowed us to profile the cognitive aspects of the interaction. A summary is presented below. For most systems visual feedback is the most important so the Cognitive Dimensions concentrate on this. Our needs are different because all of the modalities used with the student in McSig are non-visual. Therefore we have interpreted and applied the dimensions non-visually. We considered the five different interaction modalities for the visually impaired user: earcons, pan, pitch, haptic and tactile.

4.2 Evaluation Summary

It can be expected that the task of learning to write with only non-visual modalities for feedback will be a difficult task, requiring careful concentration. Here the dimension of *hard mental operations* characterises the interaction. By providing feedback with good *closeness of mapping* between the feedback and the real world, and suitably using *abstraction* mechanisms we seek to minimise the cognitive load required.

Earcons are used as an *abstraction* to indicate the start and finish of a stroke. *Error-proneness* is reduced by using two distinctive sounds for the start and finish. This helps the user to realise whether a stroke is currently being carried out or not. The *role-expressiveness* of each sound is demonstrated in that its role can be easily inferred from its order. A start sound is followed by a tone, followed by an end sound, followed by silence.

The **sound feedback** simplifies the idea of position in space into two single dimensions, creating an *abstraction*. *Consistency* is ensured by providing the same sound feedback in freedraw mode as is provided in the teaching mode. The student can measure the success of their attempts by comparing the sound feedback to that which was received when the teacher demonstrated the letter. The speech output in McSig 1.0 can only be carried out in a discrete manner, on a fully formed and accurate letter that can be recognised by the software. In comparison to this feedback, pitch and pan feedback offer better *progressive evaluation*. The user can obtain feedback on the formation of the letter for the duration of the stroke. The feedback is given in a continuous manner, regardless of the accuracy of the letter.

The *viscosity* of the **stereo pan** is low as stereo panning is readily changed between signature and single letter modes. The option to create custom versions of signature and single letter panning also demonstrates low *viscosity*. The modes are *abstractions* that each give a characteristic label to a set of behaviours for the stereo pan. Because customisation of stereo pan requires teacher input, the GUI dictates that the type of panning must be selected within teacher mode. This requires *premature commitment*, as the type of panning can not be changed once in freedraw mode. The stereo pan is inherently spatial because the sound moves between left and right speakers. This maps closely to the spatial concept that it seeks to reinforce, which is movement along the x axis. This demonstrates *closeness of mapping*. There is a problem with *consistency* because in single letter mode the starting point of the stroke is the centre of the panning, whereas with signature mode the starting point of the stroke is near the left extreme of the panning. This is a trade-off between *consistency* and *visibility*. The signature and single letter modes employ different starting points in order to maximise the non-visual equivalent of *visibility.* The single letter mode makes discerning stereo pan easier by causing panning to move sharply to the left or right when a single letter is drawn. The signature mode ensures that panning occurs across the full width of a signature, by extending the panning scope across a greater width of the workspace.

Even a small change in the **pitch** is noticeably discernable, giving this modality good "*visibility*". Low *closeness of mapping* and *role-expressiveness* is apparent as change in pitch has no inherent relevance to the concept of movement in space along a y axis; the changing pitch is an *abstraction*.

Haptic guidance demonstrates *juxtaposition*. The movement of the student's pen is juxtaposed with respect to the movement of the teacher's pen in order to mitigate *hidden dependency* of the student's pen movement upon the teacher's pen movement. The system shows resistance to change, or *viscosity*, because the device has physical constraints; the writing area size is defined by limits of the device.

The **tactile** surface allows all of the strokes that have been carried out so far to be touched, ensuring a tactile equivalent of *visibility*. Because the raised letters are persistent, and not erasable, the tactile surface has high *viscosity*, and *provisionality* is low. As a stroke is being carried out, the student can touch the tactile representation. This allows a measure of *progressive evaluation*. Two types of rubber band of different thickness can be used to show two types of line, demonstrating *diffuseness*.

4.3 Conclusions

The evaluation using the Cognitive Dimensions framework did not prompt specific changes to the implementation of the system. However, the evaluation highlighted how difficult it is to learn a signature using non-visual feedback. *Abstraction* mechanisms are carefully used to assist the student in this task and to reduce the *hard mental operations* required. The evaluation also validates a number of design choices that were made for McSig 2.0.

The evaluation reinforces that the synthesised speech feature of McSig 1.0 should not be used. Comparison with the pitch and pan feedback reveals that the synthesised speech feedback does not provide adequate feedback for partially or incorrectly formed letters.

Understanding the trade-off between *consistency* and *visibility* validates the design choice to provide different feedback for signatures and single letters. It is made clear that the possible disadvantage of lower *consistency* does not occur in isolation. Sacrificing *consistency* enables the benefit of increased "*visibility*".

Discussion of the stereo pan in terms of the Cognitive Dimensions reveals the unique nature of this aspect of sound. The decision to continue to focus on this aspect of sound in McSig 2.0 is validated. When seeking to convey spatial information with sound, the use of stereo pan is unique because it is inherently spatial. The sound moves between the left and right speakers as if it is physically attached to the student's pen. Some other aspects of sound which could be used, such as timbre, do not possess this quality.

Chapter 5

Longitudinal Study

Over a period of several weeks three visually impaired students each had ten lessons, with the goal of assisting each student to learn how to sign a signature. The three students involved are Tim, May and Nikki (The students' names have been changed).

5.1 Teacher and Observer Roles

During the lessons I played the role of both a teacher and an observer. As a teacher, I directed the lessons to facilitate the student learning a signature. McSig 2.0 was used in combination with tactile aids and pen and paper. As an observer I took careful note of the way in which the student interacts with the McSig system. Video recordings were taken of the lessons and detailed observations were written down during each lesson.

5.2 Measuring Student Progress

In order to direct lessons to support the student's learning, we need to define what constitutes good progress. The basic learning goal is for the student to learn how to sign a signature that is attractive and reproduceable. A possible way to measure progress towards this goal could be using a numerical metric for each of these qualities. This would allow statistical analysis to be carried out on the data, and could allow relatively precise conclusions to be drawn about student performance improvement. A study which used a system for teaching people how to write Chinese characters (Teo, Burdet et al. 2002) measured the closeness of match between a teacher's model character and a student's attempt at drawing the same character. The metric used was a numerical measure, calculated by moving, rotating and scaling the student's character to find a best fit to the teacher's character. The least squares difference in distances between points on the student's stroke and the teacher's stroke gives the measure of how accurately the student copied the teacher's stroke.

For the project at hand, there is no suitable numerical metric. This is due to the inherent qualitative nature of the quality of student performance. This is for a number of reasons. First, the cursive nature of writing in signatures allows for great variation while still appearing acceptable according to cultural norms. A goal could be to make letters appear similar to the ideal letter shapes. Within cursive writing, and signatures in particular, however, large variations on letter shapes are both accepted and even welcomed. For many signatures, the overall shape of the writing is relevant to creating an attractive signature, and the exact features of the letters themselves are secondary. Lastly, within the context of signatures, the quality "attractive" is highly subjective and opinion-based. The teacher has in mind a general qualititative goal, so it is appropriate for the teacher to provide a qualititative comment on progress.

As a qualitative guide for the teacher assessing progress, we can define three goals. First, the signature should be attractive in essence. Second, the signature should be reproducible with reasonable consistency demonstrated between signature attempts. This is not a firm requirement for signing documents. A moderate level of variation is to be expected. The signatures produced by the student should show major improvement in these areas. Whether a certain level of progress constitutes major progress is left to the judgement of the teacher. As an additional goal, the skill should be retained.

5.3 Research Methodology

Drew et al. (2008) describe a research methodology known as an A-B design. This is an intuitive approach for carrying out experimental research. A is the baseline condition. For the research at hand, this corresponds to a student demonstrating an initial level of performance at forming a signature that could be improved upon. B is the application of a certain treatment. This corresponds to a student being guided through lessons within the McSig environment. Should the study participant show an increase in performance between A and B, a naive approach is to attribute this increase directly to the application of treatment. This can not necessarily be inferred as any number of other variables could have affected the performance of the student.

For the study at hand, we recognise that a student's progress at learning a signature can not be directly attributed to McSig. The human factors involved are difficult or impossible to control. The small user population and practical considerations mean that a longitudinal study can not be carried out in a perfectly controlled environment. Yet, some confounds can be controlled. As all of the participants are congenitally blind, it can be safely assumed that their handwriting skills have remained predictably stable over their lifespan. A major confound would be if students carried out writing exercises on a regular basis as a part of their curriculum. We can control for this. However, eliminating all confounds relating to learning or skill aquisition is generally not achievable.

The focus of the study then, is make detailed observations on the way the student interacts with McSig. In doing so, we can articulate the ways in which McSig appears to be supporting the learning task. The case studies form a pool of rich qualitative data for analysis.

5.4 Technology Setup

Figure 16 shows the McSig equipment set up for a lesson. The teacher is seated on the left and the student is seated on the right.

Figure 16 The McSig 2.0 setup.

1. The teacher uses pen and paper to take notes of observations.

2. The teacher's laptop is placed out of the way of the student. The laptop contains the microphone which records the audio to accompany the video record of the lesson.

3. A webcam is placed approximately 30cm above the writing surface. The camera is angled towards the student's hand. It captures most of the dutch drawing board, the student's hand and part of the mechanical arm of the PHANTOM.

4. The two speakers are placed approximately 50cm apart, facing the student.

5. The PHANTOM device is placed between the speakers, with the mechanical arm and pen protruding out onto the dutch drawing board. The PHANTOM device is connected to the teacher's laptop by a firewire cable. The firewire cable connects to the laptop by a card bus.

6. The dutch drawing board is placed as close as possible to the PHANTOM device. This ensures that the rectangular working area constrains the pen

movement so that it remains on the brown rubber area of the drawing board. This prevents the tip of the PHANTOM pen from colliding with the metal and plastic edging at the top of the drawing board. The drawing board is placed at a comfortable distance from the student. Plastic tactile sheets can be clipped into place on the dutch drawing board.

5.5 Lesson Content

The content of each lesson was tailored for each student according to their skill level and current progress (Arter, McCall et al. 1996). The techniques and approaches suggested in the literature on teaching children to write (see Section 2.1) are incorporated into the lessons. Observations from previous lessons were also used to decide what should be taught.

During the early lessons, particularly the first lesson, a basic grounding is established. The student's existing skills are evaluated through discusssing basic spatial and handwriting concepts. Spatial vocabulary such as "top" and "bottom" is discussed to ensure that the student understands these (Taylor 2001). A baseline signature attempt is also collected. Where the student lacks knowledge, ideas are explained. These early lessons are also used to familiarise the student with the system.

The majority of the learning takes place in the next phase. We work through each letter in the signature, to teach the student how to write each one. Students are not taught all of the letters in the alphabet, but only the letters in their signature. Exit strokes are added to the letters where needed, to aid the transition to cursive writing (Taylor 2001). The progress of each student is tracked using a progress chart. The chart shows the date of each lesson, and the letters that the student learned in that lesson. To see if the student had retained the skill, he or she would be asked to attempt letters that they had learned in earlier lessons. When the student needed to re-learn a letter, this was noted on their progress chart.

After individual letters have been learned, the student needs to learn how to combine them into a signature. This includes learning to link the letters cursively, learning how to write along a baseline (Taylor 2001; Sassoon 2003) and making the letters the correct height (Taylor 2001).

The final stage involves moving to pen and paper to form a quality signature. The student must learn how to grip the pen (Taylor 2001), write with reduced tactile feedback and remember all the letters. During this stage, the student is moved between McSig and pen and paper to improve the signature.

5.6 Recording Observations

Data was collected by the teacher in order to allow interesting or relevant moments to be examined and recalled. The teacher takes written notes of observations throughout the lesson. Screenshots of the student's attempts at letters and a signature are collected regularly using the screenshot tool.

The entirety of teaching sessions are recorded using the Morae™ software from TechSmith (http://www.techsmith.com/), a webcam and microphone. The webcam captures video of the student's hands while using McSig or pen and paper. The Morae™ software also records video of what is happening on the teacher's Tablet PC screen. Movement of the teacher's stylus over the screen and the teacher's interactions with the McSig Teacher View graphical user interface are captured.

5.7 Ethics

Ethics approval was obtained from the University of Auckland Human Participants Ethics Committee. Each child participant and their parent/guardian was given an information sheet (see Appendix 2 and 4), explaining the purpose of the study and what is involved. The student and parent/guardian each were required to sign a consent form (see Appendix 3 and 5).

Chapter 6

Results

During the lessons observations were made about the way the students learned and their interaction with McSig. Qualitative data was captured in the form of written notes of observations, plastic tactile sheets, Morae™ videos, screenshots and the sheets of paper used for signature attempts. The observations made during each lesson are documented below.

The size of letters and signatures is important during the learning process. The students spend time learning how to scale their letters. The figures in the case studies are presented at actual size where possible.

Changes were made to the system implementation on two occassions. After two lessons with Tim, a change was made to the implementation of the screenshot tool. After a further lesson with Tim and two lessons with May, a change was made to the implementation of the pen-tip height sensing. The changes were in effect for the rest of the lessons with all three of the students. These changes are described in detail in Chapter 7.

6.1 Case Study: May

6.1.1 Student Background

May participated in the previous study with McSig (Plimmer, Crossan et al. 2008). The student is totally and congenitally blind. May was 15 years old at the conclusion of the study. She preferred to use her left hand for writing. The student is familiar with Braille, the tactile learning aids called "Wikki Stix" (see Lesson 3) and thermoform plastic (see Lesson 9). A senior teacher who is involved with coordinating May's learning regarded May's academic ability as below average for her age. The signature developed with this student consists of the letters "M Kumar".

6.1.2 Lesson 1

May was asked to carry out her best attempt at a signature using pen and paper. Through preference, she used her left hand. She was able to form a small, neat *m*, which began at the bottom left. This is shown in Figure 17. Later in the lesson she also demonstrated an *i*.

Figure 17 May's initial signature attempt, consisting of a single letter. The red dot indicates the starting point.

The student had an understanding of the concepts of left and right. The ideas of left, right, up, down, vertical and horizontal on the writing plane were quickly understood.

May remarked "there we go!" once a clear tactile marking was formed on the plastic sheet. The markings appeared to be important to her.

May had difficulty applying the appropriate pressure downwards on the plastic sheet. At one point she pushed the pen down so firmly that the PHANTOM's mechanical arm was unable to move the pen. The pen would stall, then jerk sharply in one direction, as she released it sufficiently. The result was a stroke with abrupt corners instead of a smooth curve.

The first pattern was taught, containing *m* and *r* (Figure 18).

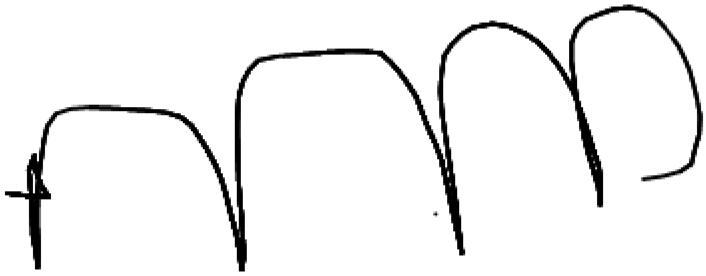


Figure 18 A pattern taught to May.

She was able to learn how to carry out the letter *r* independently. A difficulty encountered was learning how to carry out a smooth curve that tilts downwards without over-emphasising the downward curve (see Figure 19).

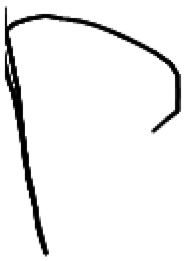


Figure 19 An *r* written by May in Lesson 1.

6.1.3 Lesson 2

The student's ability to apply appropriate pressure on the plastic sheet with the pen had improved. This was apparent early in the lesson.

I asked May if she was able to write an *r*. The attempt is shown in Figure 20. The student appeared to have confused the *r* with an *m*.

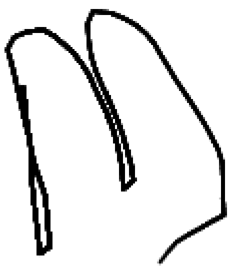


Figure 20 An unsuccessful attempt at *r*.

May quickly re-learned a correct *r* using McSig.

After 30 or 40 minutes of having the letter *a* demonstrated, making attempts, and receiving feedback from me, May could do a fairly good *a* (see Figure 21). The curves in the *a* tended to be square edged and this was difficult to overcome. While learning *a*, the student began to ask "Can I try?" This indicated that the student was confident and was engaged with the task. It also showed that the student was familiar with the purpose of the teaching and freedraw modes, and understood that the teacher needed to initiate a change in modes.

Figure 21 Two good attempts at *a*. The curves could be improved by being smoother.

Problems were seen with the robustness of the pen tip height sensing during this lesson.

6.1.4 Lesson 3

The lesson focussed on learning the letter *u* and revising the letter *r*.

To begin with, May had no knowledge of how to form a *u*. She emphasised the features of the letter incorrectly. This is shown in Figure 22.

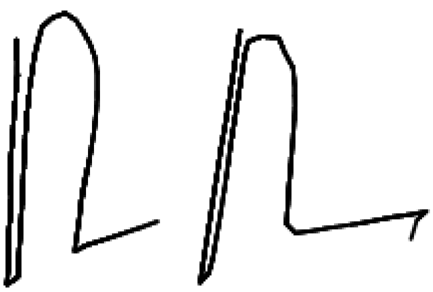


Figure 22 Two attempts at u, with features emphasised incorrectly.

“Wikki Stix”, shown in Figure 23, are a physical tactile aid that can be used to demonstrate letter shapes. Each stick consists of a fibrous centre surrounded with wax. The sticks can be bent into letter shapes which can be felt by students. The Wikki Stix website suggests a number of applications for use with visually impaired students (http://www.wikkistix.com/sightimpaired.php).

Figure 23 Wikki Stix (retrieved from http://shop.trcabc.com/Rainbow-Wikki-Set-24pc-in-6/A/B000WFLRFK.htm)

“Wikki Stix” were used to show the shape of the *u*. I bent a stick into the shape of a *u* and laid it on the table surface. May was able to feel the shape of the letter.

May was able to produce a visually appealing *u* by the end of the lesson (see Figure 24).

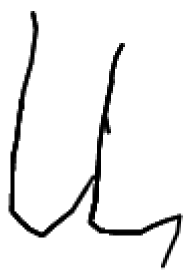


Figure 24 May’s successful attempt at *u*.

When asked if she could remember how to do an *r* from the previous lesson, May said she could not. After I guided her through the motion of the letter once using McSig, she asked “Can I try?” She carried out a good *r*. While practising writing *r*’s May began to lose concentration. Fourty-five minutes into the lesson the attempts at *r*'s suddenly became poor.

6.1.5 Lesson 4

May was asked if she could remember how to write a lowercase *u*. She could not. Using the McSig system, May was able to quickly re-learn the letter. I drew the letter *u* once. The student then attempted the letter shape, but was not successful. I guided the student around the letter shape once more, and the student was then able to produce the letter successfully.

The letter *r* had also been forgotten. After having the letter *r* demonstrated a number of times, the student was able to re-learn an *r*.

Two lines were used to demonstrate the difference in height between an uppercase and lowercase *m*. When the lines were added to the drawing board, May spent around 25 seconds feeling the lines to orient herself. This is shown in Figure 25.

Figure 25 May feeling the tactile lines.

The lines were a useful tool for communicating the spatial concepts. The student remarked "I like the rubber band lines!"

6.1.6 Lesson 5

May was able to produce an uppercase *K* after it was demonstrated using McSig. After it was demonstrated approximately another three times, the student was able to write the letter more attractively. The student began to draw the letter with a curved stroke (see Figure 26). The student said that she "liked the curved bit". This kind of personal style is appropriate for a signature.

Figure 26 May's preferred version of *K*.

During this lesson May attempted to actively move the PHANTOM pen during the teaching mode, rather than playing a passive role and having her hand guided around.

6.1.7 Lesson 6

During this lesson May again moved the PHANTOM pen while I was demonstrating a letter. The student appeared to be moving the pen in the direction where she thought the letter would go.

May made an attempt at doing an uppercase *K*, but the letter was malformed. She was able to re-learn the letter. After re-learning the letter, she would sometimes forget how to do it.

The lesson focussed on joining together several letters cursively. May still needed verbal instruction to guide the student around the formation of the letter shapes. For example, I said "around, up, down, flick" to assist the student forming an *a*. The student was accustomed to writing an *m* using an alternative method (see Lesson 1). When this alternative form of *m* follows the letter *u* cursively, the *m* is raised up higher than the surrounding letters, as shown in Figure 27.

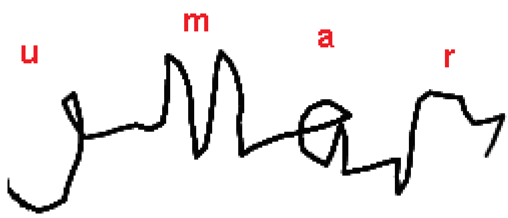


Figure 27 An alternative form of the letter *m* causes a problem when it is joined cursively.

The student was re-trained to do the *m* starting from the top left with the first stroke proceeding downwards until it reaches the baseline. While making this adjustment, the letters produced were sometimes too tall and thin. This was unable to be improved upon during the lesson time.

6.1.8 Lesson 7

For the first time, May used pen and paper. A standard ballpoint pen was used. May was not confident to do the letters *u* and *a*. She could successfully do an *m*. After verbal prompting, she was able to carry out an *r*.

A pipe cleaner was bent into the shape of the letter *u* to demonstrate the shape of the letter. May wanted to trace the tip of the ballpoint pen around the shape of the letter whilst feeling the pipe cleaner with the non-writing hand. She was able to form a reasonably accurate *u* with pen and paper. While repeating the *u* for practice, an unusual form of the letter arose (see Figure 28). A loop was introduced into the letter.

Figure 28 An unusual form of u.

The letter was demonstrated with McSig. After this demonstration, the student carried out a much improved *u* (see Figure 29). A remaining issue with the letter formation was the noticeably square corners, which we could not improve upon during the lesson time.

Figure 29 An example of a *u* with sharp bends instead of a smooth curve.

May quickly re-learned how to do the letter *r* using McSig. She enthusiastically remarked “I like those *r*’s”.

6.1.9 Lesson 8

The task for this lesson was to work through cursively joining a sequence of letters, “*umar*”, which appears at the end of May’s signature. Verbal instruction was provided to aid the student’s attempts. When May was part way through the full sequence of letters she said “I’ve lost it”. Carrying out the signature while remembering which letter she was up to clearly required careful concentration.

Demonstration and attempts were carried out using McSig until May could do a satisfactory attempt. We then moved to pen and paper, where May performed well. The student needed reminding to start the letter *m* from the top left (as was learned in Lesson 6).

While practising the sequence of letters, May needed to be told that the *r* did not require a flick as it was at the end of the signature. While practising, she also carried out an attempt with big long flicks (see Figure 30).

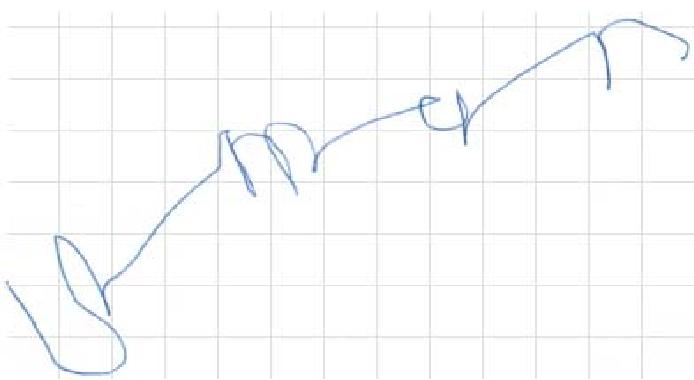


Figure 30 May’s signature with long flicks.

May mentioned that she needed to learn how to sign for an upcoming event.

6.1.10 Lesson 9

At the start of this lesson, May was able to carry out an uppercase *M* and the sequence of letters "*umar*" with no prompting or assistance. This demonstrated fantastic retention of the skills.

The remaining letter to master was an uppercase *K*. The student found this a difficult letter. An alternative form of the letter was explained which could help make it easier to write. This is shown in Figure 31. Thermoform plastic was used to demonstrate the alternative form in a tactile manner. Writing on thermoform plastic with a pen forms a ripple which can be felt by the student. May found the alternative form confusing. She eventually learned to do a satisfactory *K* using a conventional form.

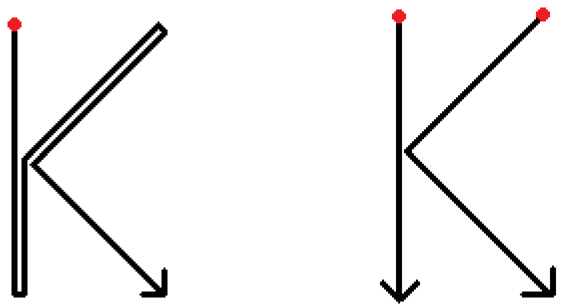


Figure 31 A conventional and alternative form of an uppercase *K*

May was asked to repeat the entire signature several times using pen and paper. Verbal prompts were provided at first. As May improved, less assistance was provided. The student eventually did a full signature with no assistance (see Figure 32). The signature was angled across the page.

Figure 32 May's signature, written with no assistance provided.

The student noticed that pushing down firmly with the pen on the paper results in a groove that can be felt. She remarked "hey, you can actually feel that!"

Post-it notes were then used as a guide. May was able to feel the post-it note and use its top edge as a tactile baseline. This helped her to keep the signature lined up along the baseline.

6.1.11 Lesson 10

It was observed that May had a good pen gripping technique. This allowed her to control the pen well.

While May was signing a signature, the exit stroke of the *a* ended too close to the baseline. May appeared to realise this. She lifted her pen off the paper (at Point A in Figure 33), moved it upwards to a new starting point (Point B in Figure 33), and carried out a great *r*. This demonstrated fantastic spatial awareness.

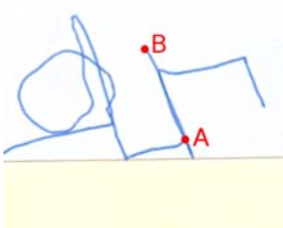


Figure 33 May repositioned her pen to make sure that the *r* was correctly placed.

May also devised a new form for the letter *K*, starting from the bottom left. This further demonstrated her spatial awareness.

The letters formed were slightly too large. Early attempts at making the signature less wide resulted in the letters running into each other.

During this lesson, May was able to form an attractive signature neatly along a baseline with no verbal assistance (see Figure 34).

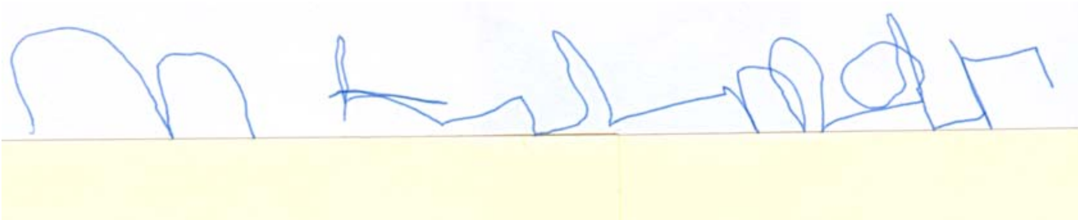


Figure 34 Signature written on a line with no assistance.

6.1.12 Summary of Progress

McSig assisted May in learning the letters *K*, *u*, *m*, *a* and *r*. She successfully learned how to join the sequence of letters "*umar*" cursively. She was able to successfully sign a signature with no verbal assistance, using a post-it note as a guide. During the final lesson, May demonstrated fantastic spatial awareness, repositioning the pen tip in order to draw a letter correctly.

6.2 Case Study: Nikki

6.2.1 Student Background

Nikki was a participant in the original McSig study (Plimmer, Crossan et al. 2008). She is totally and congenitally blind and was 13 years old at the conclusion of the study. She wanted to use her left hand for writing. Nikki uses Braille and she also mentioned that she uses a tactile drawing board. The student mentioned that she previously signed her name using "N T". The signature suggested to Nikki was "N Te Paa" and she requested that the letter *J* be added to make it "N J Te Paa". A learning coordinator familiar with Nikki regarded her as an able student, with academic ability equivalent to the average for her age. The student had an existing understanding of the spatial concepts "diagonal" (see Lesson 1), "cursive" (see Lesson 2) and "portrait" or "landscape" (see Lesson 3).

6.2.2 Lesson 1

Nikki's initial writing skills were at a relatively high level. When asked to carry out a signature, she made an attempt at each letter (see Figure 35). Each letter beared some resemblance to the intended letter. The *N* was satisfactory. The *T*, *e*, *P* and *a* were all malformed or disproportionate in some way.

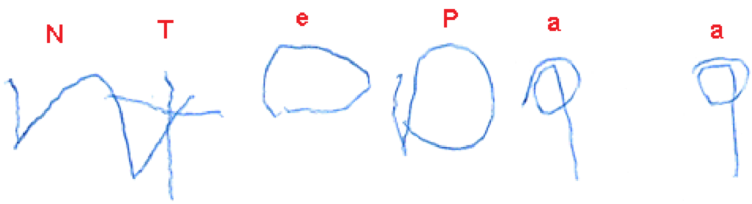


Figure 35 Nikki's initial signature.

Nikki immediately appeared to be a confident learner. A number of questions were asked and comments were made. She requested for a *J* to be included in the learning. During familiarisation with the system Nikki asked if I have a pen. She also enquired about the earcon at the end of each pen stroke, asking "What is that?"

Nikki applied her musical knowledge to understanding the system. A comment was made that the sound feedback in the y axis may have been spanning over an exact octave, or perhaps nine notes.

Nikki was familiar with concepts such as left, right, up, down, vertical and horizontal. When I mentioned that a diagonal stroke we were learning was orientated "kind of up, kind of right", Nikki quickly recognised this concept and mentioned the term "diagonal".

When attempting to learn an uppercase *J*, Nikki remarked that it had a "little tail". She also said that it was "a bit like an umbrella". She explained to me that she knows this because she has felt an umbrella before. Nikki was able to learn how to do a *J* within the lesson.

6.2.3 Lesson 2

Nikki couldn't remember how to do a *J* from the previous lesson. After being guided through the letter with McSig she was reminded of the letter.

It was apparent throughout the lesson that Nikki wanted to choose her own starting position for the pen when forming a new letter.

When I was explaining how a flick after a letter can be used to link the letter to the next letter, Nikki asked "Oh, you mean cursive writing?" As we worked on learning the *a*, she asked if the version we were learning was uppercase or lowercase. Nikki was able to successfully learn how to write an *a*. Two cursive *a*'s appear at the conclusion of Nikki's signature. The formation of these was demonstrated.

During this lesson, it was observed that Nikki usually held the pen almost vertically.

6.2.4 Lesson 3

Sometimes we would rotate the drawing board in order to make it easier to find unmarked space on the plastic sheet. Nikki correctly used the terms "portrait" and "landscape" to describe the orientation of the drawing board.

The focus of this lesson was to learn how to write two lowercase *a*'s linked cursively. A pipe cleaner was used to demonstrate the shape of this formation. The pipe cleaner was bent into shape and was felt by the student. An emphasis of the lesson was learning how to curve the flick of the first *a* upwards and letting the curved piece of the second *a* fall beneath this flick. The flick needed to be angled up sharply enough to prevent the second letter from falling below the baseline. Eventually Nikki could carry out good cursive *a*'s (see Figure 36).

Figure 36 Nikki's attempt at cursive *a*'s

6.2.5 Lesson 4

The letter *T* in Nikki's original signature attempt (see Figure 35) needed work. I asked Nikki to write a T and she did well. She was able to form the letter by making a vertical stroke, lifting the pen, then doing the horizontal stroke across the top.

Nikki improved her skill at writing *P* using McSig. A challenging part was to get the curved part of the letter smooth and nicely shaped.

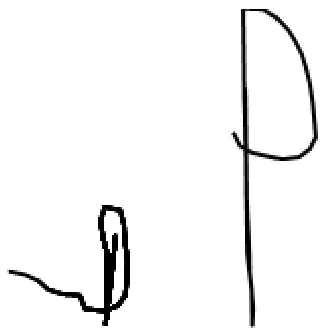


Figure 37 Nikki's initial and final attempts at *P*

We used a single tactile rubber band line to introduce the idea of writing on a baseline. An uppercase *T* was demonstrated and it was explained that the bottom of the letter should rest on the line.

Nikki was also able to improve her *e* during this lesson.

6.2.6 Lesson 5

Nikki was asked if she could remember how to write two *a*'s joined cursively. She asked to be guided around them. Once she had been guided through the motion with McSig, she was able to carry out the formation well.

Nikki asked whether we were currently in freedraw mode. I asked whether she found it difficult to know which mode we were in. She said that she listened to what I was saying to determine which mode we were in.

Nikki was able to write an *N* neatly to begin with. Two rubber band tactile lines were introduced to use as a spatial reference. As the student was forming the diagonal stroke of the *N*, she asked if the stroke should continue all the way to the baseline. I told her that it should. Upon finishing the letter, it was explained to the student that the letter was too wide. This was because of the angle that the diagonal stroke was on. The letter attempt is shown in Figure 38.

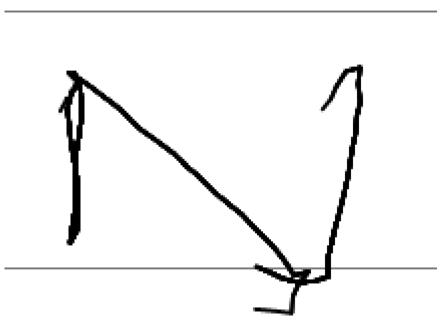


Figure 38 An uppercase *N* that is too wide.

Nikki learned to project the diagonal line on a more appropriate angle, resulting in a well-proportioned letter. The two tactile lines were moved closer together to encourage Nikki to form the letter smaller. She was able to scale the letter to fit the new required height.

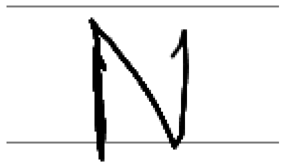


Figure 39 A well-formed and scaled-down uppercase *N*.

Nikki made a mistake while attempting a *J*. She was aware of the mistake and knew how to correct it. In a further attempt she was able to write a very neat and well formed *J*.

6.2.7 Lesson 6

After we revised the *N* and *J*, Nikki made an attempt at writing a complete signature using the PHANTOM pen. A rubber band tactile line was used as the baseline and the top of the Dutch drawing board formed a physical boundary which acted as the top line. The signature attempt went well. The student needed verbal assistance in order to complete the letters *e* and *P*.

Nikki began to use a pen and paper during this lesson. A separate piece of paper was placed on top of the paper so that its top edge could be used as a guide. It was too difficult for Nikki to hold the paper in place, so it was attached using blue-tack. As she was writing the signature shown in Figure 40, Nikki forgot the order of the letters. The writing surface was slightly rough, so I noted that the paper should rest on other sheets of paper for the next lesson.

The student commented that when using McSig, she can tell when the letters are intersecting and overlapping, but when writing with a pen, she could not tell, because of the lack of tactile feedback.

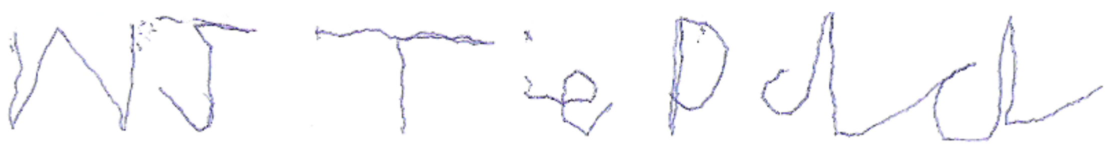


Figure 40 Nikki's first attempt at writing a signature with pen and paper.

6.2.8 Lesson 7

Nikki was given the letters of her name which had been bent out of pipe cleaners. She suggested that the pipe cleaner letters “will be really useful, I think”.

Nikki mentioned a life situation where she could use her signature. She appeared highly motivated to improve her skills. She mentioned that she practises her signature at home.

It was explained to Nikki that the ink that comes from the pen is wet, so she should avoid touching or rubbing the letters as they are being written. This could potentially frustrate Nikki as the she naturally tries to feel the paper for any available tactile feedback while writing with a pen.

The top edge of a post-it note was used as the baseline, and the top of the sheet of paper as the top line. So that Nikki could learn how to scale letters smaller, she was asked to form the letter *N* three times. The post-it note was moved progressively closer to the top of the page each time.

Nikki then made three attempts at a full signature by writing in the gap between two post-it notes. These attempts were good attempts.

The student made a mistake with the *T* and *P* (shown in Figure 41), but was aware of the mistake and how to correct it in both instances.

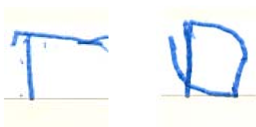


Figure 41 The attempts at *T* and *P*.

It was observed that Nikki was pushing down very hard with the pen.

I asked Nikki if writing her signature required lots of concentration. She emphatically replied that it takes a lot of concentration because "you don't know if you're doing it right".

6.2.9 Lesson 8

This lesson focussed on carrying out four attempts at writing a signature, using a post-it note as a guide.

During one signature attempt, the student asked if the letter *e* was formed by moving the pen "across, up, down, around". She had trouble remembering which letter to do next. She also had difficulty estimating where to begin the letters. The student expressed that it was difficult because she could not tell whether letters were colliding or not.

I observed that Nikki was constantly feeling the impression left by the pen on the paper with the non-writing hand. The resting paper below allowed a large groove to be formed in the paper by the pen.

The pen-tip would occasionally hit the post-it note before Nikki intended it to, causing a portion of the letter shape to be flattened or squashed.

Nikki asked me whether she was at the correct starting height for almost every letter. I would tell her if she needed to move the pen upwards or downwards. Nikki depended on this feedback to get the letters the correct height. During some attempts, a trend was apparent in that Nikki would draw each letter larger than the previous letter as she moved along the signature. This is apparent in Figure 42.

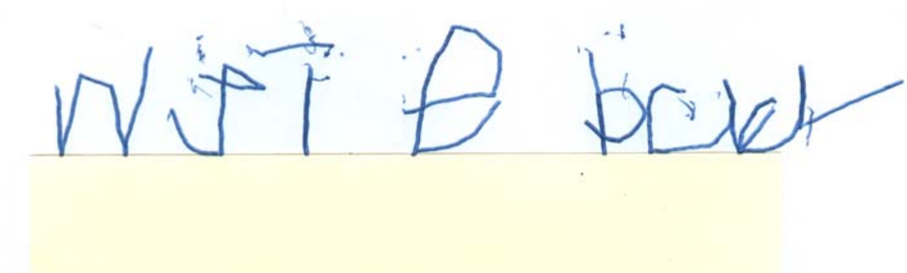


Figure 42 The heights of the letters varied.

A rest between the third and fourth signature attempts appeared to be beneficial. The student seemed to have renewed concentration. She formed the letters in the fourth attempt more neatly.

6.2.10 Lesson 9

Further attempts at a full signature were carried out using pen and paper, in an attempt to improve Nikki's estimation of the height of letters, her ability to remember the order of letters and the overall quality of her signing.

During the first signature, the student forgot which letter she was up to. The *J* was slightly malformed, so Nikki was asked to practice by writing another *J*, focussing on correct formation.

For the second signature, the student was told that no verbal feedback would be provided about how high to start the letters. She signed a good signature (Figure 43).

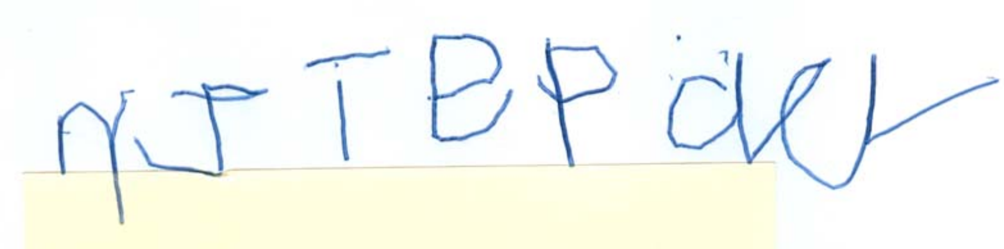


Figure 43 Nikki's signature, signed without verbal assistance.

During another signature, I observed that the tactile sense was being depended upon heavily. I asked the student "How do you think you would go if you couldn't feel anything?" She responded "terribly".

It became apparent as Nikki wrote signatures that her method for estimating the height of letters was not reliable enough. Nikki held her finger above the signature and began writing a letter from underneath the finger. This was not reliable because there was no spatial anchor to use to keep the height consistent. I suggested measuring the height of the starting points of letters with respect to the post-it note. The pad of the index finger could be placed over the edge of the post-it note so that the edge of the note could be felt. Once the finger was suitably positioned, the top of the finger could be used as the vertical starting point for the letter.

Nikki had difficulty doing lowercase letters because they were too small. On reflection, I decided that the student's pen gripping technique made it significantly more difficult to control the pen, especially for smaller letters. Figure 44 shows the problematic gripping technique.

Figure 44 The problematic gripping technique.

All of the signatures carried out during this lesson generally had uppercase and lowercase letters at a similar height.

6.2.11 Lesson 10

A focus of this lesson was for Nikki to learn a new pen gripping technique. Another focus was to practice signing a signature with the aim of improving the overall neatness and quality.

A plastic grip was placed on the pen to teach Nikki how to hold the pen. She is shown using the grip in Figure 45. The student found it difficult and uncomfortable to use at first, but became accustomed to it. Once the grip was removed, she was able to continue holding the pen with the new gripping technique that the plastic grip encourages. This is shown in Figure 46. Nikki remarked that the new gripping technique “does feel a lot more controlled”. Nikki used the ridges on this particular ballpoint pen to determine how far down the pen to hold it.

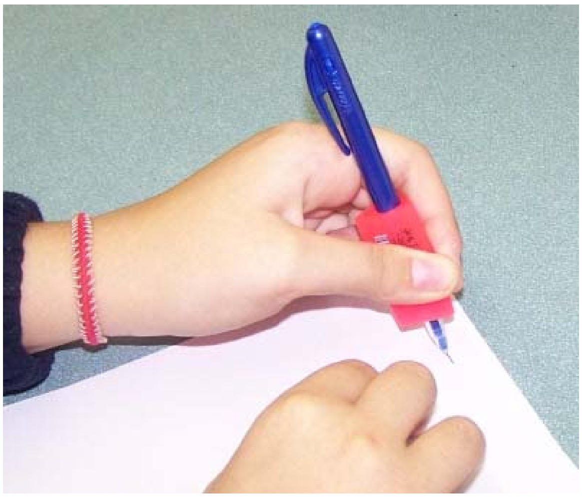


Figure 45 Nikki using the pen grip.

Figure 46 A new pen grip with improved control.

After training on how to grip the pen, six signatures were signed by Nikki using a post-it note as a guide. An example is shown in Figure 47.

Figure 47 A signature signed by Nikki after training on how to grip the pen.

6.2.12 Summary of Progress

Nikki approached the learning task with enthusiasm. McSig assisted her to improve the appearance of each letter in her signature and learn the additional letter J. She was able to master cursively joining two *a*’s at the end of her signature. The student also learned to grip the pen well and scale the signature down to a reasonable size.

6.3 Case Study: Tim

6.3.1 Student Background

Tim was a participant in the first McSig study (Plimmer, Crossan et al. 2008). He is congenitally blind. Tim’s vision included some sensitivity to light and dark. Tim was 14 years old at the conclusion of the study. He did not have a preferred writing hand. We began by using the right hand. Tim can read Braille. The signature that was being developed with Tim was “T Pearse”. A coordinator responsible for directing Tim’s learning mentioned that Tim experienced some learning difficulties academically. She also mentioned that sometimes Tim would have particular difficulty with recall and retention.

6.3.2 Lesson 1

Tim carried out an initial attempt at a signature using pen and paper. This is shown in Figure 48. It was apparent that he had skills at forming a basic *T*. All of the letters attempted were placed on top of each other. Tim had no concept of moving his hand rightwards across the page when writing the letters in a word.

Figure 48 Tim's initial attempt at a signature, with letters formed on top of each other

Tim also produced some attempts at letters that were not recognisable.

It was explained to Tim that the *ar* contraction found in Braille needed to be separated out into two letters when writing a signature. This was easily understood.

When using the PHANTOM, Tim held the pen very lightly, and was reluctant to apply pressure downwards onto the plastic sheet. Tim was interested in the mechanical arm of the device. He was told that he needed be most interested in what the tip of the pen was doing. Tim asked if the laptop was connected to the PHANTOM pen.

Tim said that he liked the sounds and did not find them distracting.

Tim had a good understanding of the concepts up, down, left, right, vertical and horizontal.

Tim made good progress at learning an *e*.

At the end of the lesson, I asked Tim "how was that?". He replied "it was very good". He also appeared to have enjoyed the lesson.

6.3.3 Lesson 2

At one point early in the lesson, Tim appeared to lose concentration on the learning task and began to move the pen around in circles repeatedly. He seemed to be interested in exploring the sound feedback from the device. In this case, it was clearly a distraction. At one point Tim started humming songs along with the sound feedback.

Tim's loose grip on the pen needed to be improved. He was given pen and paper and he practised holding the pen tightly enough. I provided verbal instruction.

Tim's original attempt at a *T* needed improvement (see Figure 49). By using McSig, he learned how to form a more complete *T*, with the horizontal line extending further towards the left.

Figure 49 An initial attempt (left) and improved attempt at *T*

When he began to learn how to write an *r*, Tim formulated his own "chant" to remember the letter: "down, up, right, little-bit-down".

Before receiving any instruction on the letter *a*, Tim was able to write a version of the letter that was a reasonably good in terms of the direction of each stroke. This is shown in Figure 50.

Figure 50 Tim's initial attempt at *a*.

I demonstrated the letter to Tim with an exit stroke included. The student was able to make good progress with the new letter formation. His improved *a* is shown in Figure 51.

Figure 51 An improved version of the *a*, written by Tim.

We briefly looked at the idea of the *a* being attached to the *r* cursively, but this seemed to be an advanced concept for Tim at this stage.

During teaching mode, Tim had difficulty applying a suitable amount of pen pressure. Sometimes he would push down too lightly and no mark would form on the plastic. Other times he would push down too hard, so that the PHANTOM mechanical arm was unable to move the pen.

A difficulty with capturing screenshots of the student's attempts was particularly apparent during this session. When the student carried out an attempt that was particularly interesting, I would push the screenshot button and a screenshot of the canvas would be saved. A problem arose when the student continued writing soon after this, before I had a chance to clear the canvas manually. Further interesting examples may arise, but they are intertwined with and overlapping the older strokes.

6.3.4 Lesson 3

During this lesson, we worked through learning, revising and improving the letters *T*, *a*, *r* and *e*. Chants such as “around, up, down, flick” served as a memory aid. Tim was good at *T* and made good progress with *a* (compare Figure 52 and Figure 53) and *r* (see Figure 53). The *e* was still difficult for Tim at the end of the lesson.

Figure 52 An early attempt at *a*.

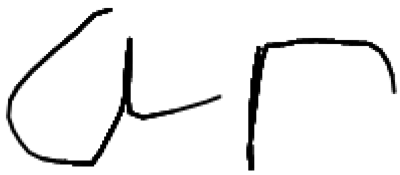


Figure 53 Successful attempts at *a* and *r*.

One sheet of plastic was used by Tim, and he seemed indifferent when the markings on the plastic overlapped.

6.3.5 Lesson 4

Learning how to write an *s* was assisted by the use of a chant “left, right, left”. Earlier in the learning process, Tim did an *s* that was too wide. This is shown in Figure 54.

Figure 54 A wide *s*.

After my verbal instruction and practice using McSig, he was able to do a good *s* (Figure 55).

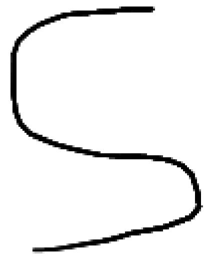


Figure 55 A good *s*.

I demonstrated an uppercase *P* for the first time using McSig. I suggested using "down, up, around" to remember the letter. Tim changed this to "down, up, right, left". Each attempt at the *P* was slightly malformed, with the enclosed region of the letter being either too small or too large (see Figure 56). However, Tim's attempts at the letter demonstrate good progress.

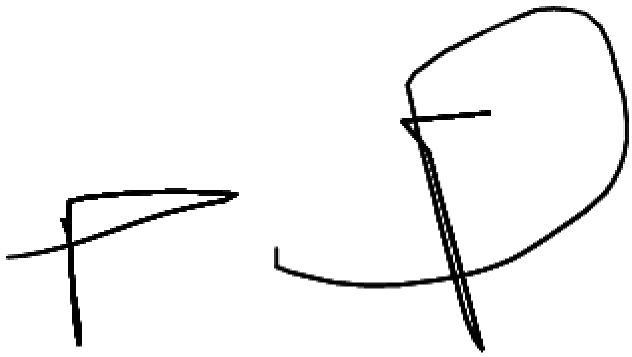


Figure 56 Attempts at the letter *P*.

6.3.6 Lesson 5

Tim could not write an *e* at the start of the lesson. He devised the sequence "right, up, left, down, flick" to remember the letter. This appeared to be very helpful and the student was then able to write a well-formed *e*.

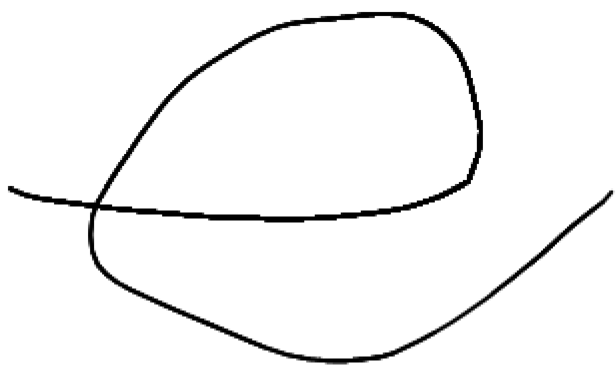


Figure 57 A well-formed *e*.

Tim then learned how to write the *T* and *P* next to each other (the two letters appear one after the other in his signature). He was asked to write the letter *T*, then move his hand rightwards slightly, then write the letter *P*. At first he left a gap between the letters that was too wide. I suggested he placed them a finger width apart. This is an appropriate gap for the large-scale letters that were being written.

Tim was asked to write an *a*, to give me an indication of how well he had remembered it. Tim produced the *a* in Figure 58. He had retained knowledge of the *a* fairly well.

Figure 58 An unassisted attempt at *a*.

McSig was used to improve Tim's skill at writing *a*. An improved *a* is shown in Figure 59.

Figure 59 An improved version of *a*.

6.3.7 Lesson 6

This lesson concentrated on revising the *e* and *a*. When asked if he could remember these letters, Tim said "I think so". Attempts at the *a* were generally well-formed. Tim found it difficult to write a good *e*. There was a large variation in the quality of attempts at *e*. An unsuccessful *e* is shown in Figure 60.

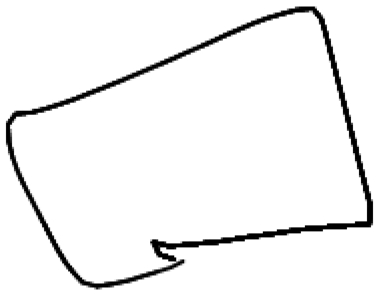


Figure 60 An unsuccessful *e*.

Tim was asked to try writing each of the letters that he could remember from his signature. At this stage of the lesson, it appeared that the student's attention span had been exceeded. The letter attempts were not successful and the order of the letters was forgotten.

During this lesson it was observed that Tim appeared to move the PHANTOM pen himself during the teaching mode.

6.3.8 Lesson 7

A rubber band tactile line was used at the start of this lesson. Tim practised writing a *T* so that the bottom of the letter touched the line.

Tim could not remember how to write a *P*. He thought that it might be described by "right, up, left, down" and said that he could not remember it very well. He was able to improve his attempts at *P*.

Tim was curious about the tactile surface and asked if the markings on the tactile sheet could be erased.

Tim could remember how to do a fairly good a. After verbal prompting, he was able to produce an *e* and *r*. He had difficulty with writing an *s*.

6.3.9 Lesson 8

A pipe cleaner bent into the shape of a *T* was given to Tim to feel. This was used to reinforce the correct shape of the letter. Tim was then asked to write the letter *T* using pen and paper and did fairly well.

After some demonstration with McSig, Tim was asked to do a *P* and produced a malformed version of the letter. My verbal instruction and feeling a pipe cleaner version of the letter did not seem to help. When I demonstrated the letter further using McSig, the student said “Oh! I get it”. The student was then able to write a well-formed *P* using pen and paper.

Figure 61 A *P* written by Tim.

We began working on the *e* using McSig. The student appeared to have lost concentration so no real progress could be made.

6.3.10 Lesson 9

During this lesson, we moved between using McSig and using a ballpoint pen. Where a letter needed to be revised, we would use McSig to revise it. A ballpoint pen would then be used to attempt writing the letter on paper.

A post-it note was used as a guide and Tim practised writing the letter *T* so that it rested on the top edge of the note. A second post-it note was added, to form a tactile baseline and top line. The student tried writing a *T* and *P* between the lines.

Tim’s pen gripping technique needed to be improved. By learning to rest his hand on the paper, he was able to more carefully control the pen.

While attempting to write a *P*, Tim began to depend on the “down, up, right, left” chant as if that was his only recollection of the letter. This resulted in a malformed letter. The relevant detail of the curvature of the *P* is lost. This is apparent in Figure 62.

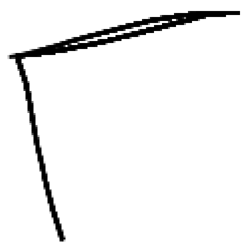


Figure 62 A malformed *P*.

After practice, Tim was able to improve on this attempt slightly.

Moving quickly between McSig and a ballpoint pen seemed to be highly effective at assisting Tim to revise *e* and *a*. We would use McSig for a short period, then move back to using pen and paper. A dramatic improvement was shown for both of *e* and *a*. The student formed attractive, fully-formed versions of the letters. Figure 63 and Figure 64 show the improvement seen when using this approach.

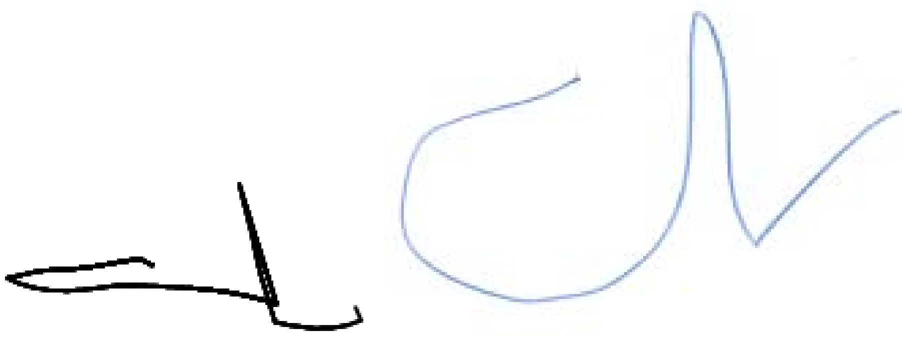


Figure 63 The initial *a* (left) and excellent final *a* written by Tim.

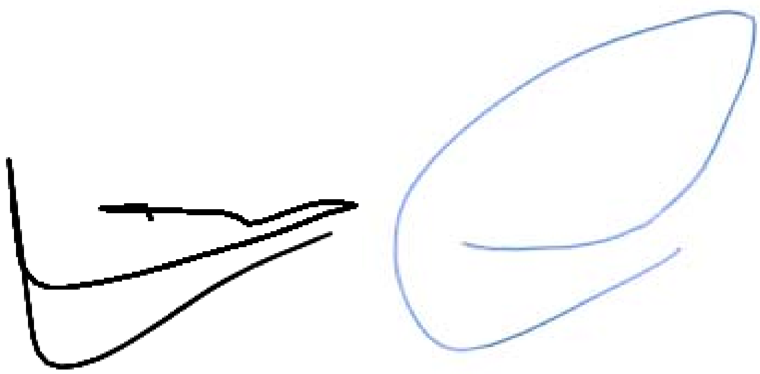


Figure 64 The initial *e* (left) and excellent final *e* written by Tim.

Tim was asked to attempt his entire signature. The first attempt had a recognisable *T* and *P* and *a*. The other letters were not well-formed or were omitted.

For the second attempt at a signature, Tim had lost concentration. He began to guess how to do a letter using what appeared to be random permutations of the directions up, down, left and right.

6.3.11 Lesson 10

During this lesson Tim carried out attempts at letter shapes using pen and paper, and McSig was also used.

Tim's pen holding technique was good.

The student could do *T*, but had considerable difficulty with *P*, *e*, *a* and *r*. Some of the problems seemed to be the result of depending on the left, right, up, down memory technique. The student also had a noticeable lack of concentration and patience.

Tim was curious about ink from a ballpoint pen. He wanted to know why he couldn't feel it.

It occurred to me during this lesson that the movement of the PHANTOM pen from its original starting point to the starting position of a letter could be perceived as part of the letter by the student. This is particularly pertinent for Tim, who was often not interested in the tactile feedback provided by the plastic sheet, or would not form markings on the sheet. Had more attention been paid to these markings, Tim could have determined which strokes were truly a part of the letter.

A post-it note was placed close to the top edge of the page. Tim was asked to write a *T* between the top edge of the post-it note and the top of the page. The post-it note was then moved closer to the top of the page before the letter was written again, to encourage Tim to scale the letter smaller.

When attempting to re-learn the *a*, the student formed an unrecognisable version of the letter (Figure 65). When I asked Tim if he was happy with it, the student replied "yes".

Figure 65 Tim's attempt at *a*.

Tim's final attempt at a full signature (Figure 66) contained a well-formed *T* and *P*. He could also write a good *e* at this point. Tim still needed me to prompt him with the name of each letter.

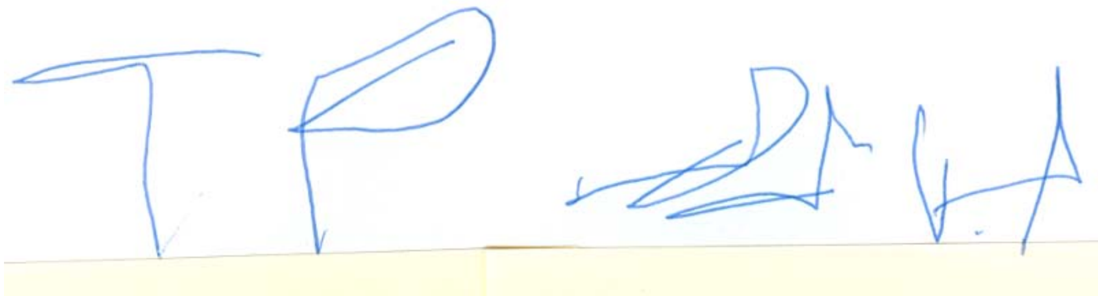


Figure 66 Tim's final attempt at a signature.

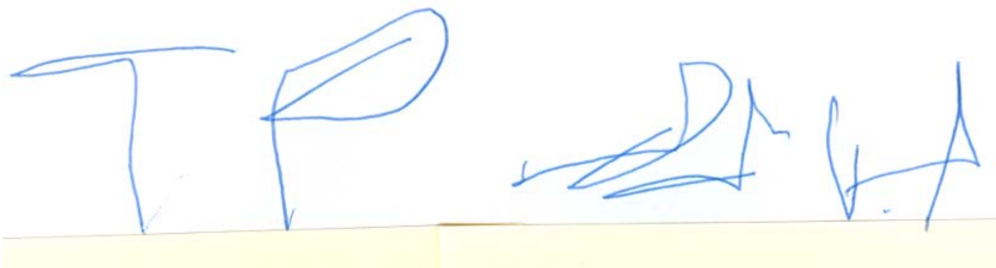
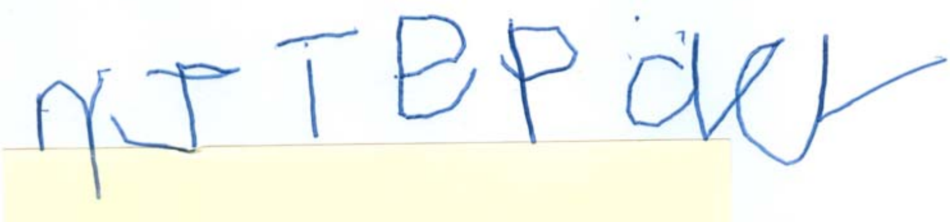
6.3.12 Summary of Progress

Tim seemed to enjoy exploring the McSig system. He commented favourably on the system in Lesson 1. The system also appeared to be greatly assisting his learning. During Lessons 2, 3, 4, 5, 8 and 9 using McSig, Tim's attempts at writing particular letters were noticeably improved over his attempts earlier in the lesson. Tim was generally not very interested in the tactile feedback provided by the plastic tactile sheet. This was apparent in Lesson 3.

Tim seemed to have difficulty remembering letters. Although he learned to write many of the letters very well during lessons, he was unable to remember all the letters during later lessons. His final signature attempt in Lesson 10 (Figure 66) demonstrates this. This difficulty with retention can be understood in the context of his general academic ability. His learning coordinator made mention of learning difficulties and specific problems with retention and recall (see Section 6.3.1).

6.4 Summary of Student Progress

From the three students in the study, May and Nikki demonstrated fantastic progress. Each was able to carry out a visually-appealing signature independently by the end of the lessons. Tim made some great progress within individual lessons, but had difficulty retaining the skill. Table 2 summarises the progress of each student during the study. The "before" signature is the baseline attempt carried out by each student during their first lesson. The "after" signature is one example of an attempt carried out during a later lesson.

Tim Before	
Tim After	 Note: verbal prompting was provided.
Nikki Before	
Nikki After	

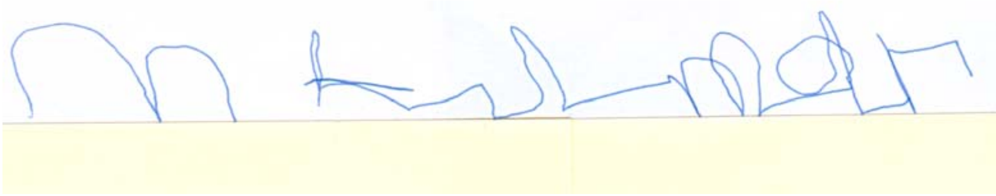
May Before	 Note: the red dot indicates the starting point.
May After	

Table 2 The "before" and "after" signatures for each student.

Chapter 7

Discussion

7.1 The Learning Experience

The task of learning to write involves three sub-tasks. The student needs to learn the shape of the letter. The motor skills to learn the letter must also be developed. Finally, the student needs to retain the learned skill. McSig appears to be greatly beneficial in assisting the student through a learning process involving these tasks.

McSig was able to assist particularly in the area of motor learning. The haptic guidance provided by the system plays a unique role in directly demonstrating the movement required to form the letter.

Using a combination of physical tactile aids, McSig and paper proved the most beneficial for the students' learning. To teach the students the shape of the letters, pipe cleaners and "Wikki Stix" were sometimes provided for the students to touch (For example, May in Lesson 3, Nikki in Lesson 7). During Tim's Lesson 9, McSig and a ballpoint pen were used in quick succession. Tim showed a dramatic improvement in a short space of time with the letter *a* (Figure 63) and *e* (Figure 64). In Lesson 8 a similar approach seemed beneficial for May.

The pre-writing exercise of forming repeating patterns, described in the literature on teaching children to write (Taylor 2001; Sassoon 2003), was found to be unhelpful. When the entire alphabet is being taught, the patterns may be of more use, as they could be used to develop the skills for a number of letters which are grouped according to their shape. When teaching a signature, only a small number of letters are taught. When learning a small number of letters, the patterns introduce potential for confusion.

Nikki relied heavy on tactile feedback even after moving to pen and paper. In Lesson 7, Nikki was pushing hard on the paper with the pen. In Lesson 8, it was observed that she was feeling the groove left by the pen on paper to assist her writing. In Lesson 9 Nikki said that she thought she would do badly without the tactile feedback. This demonstrates the concern expressed in motor learning literature (Feygin, Keehner et al. 2002) about a learner becoming dependent on additional feedback. Clear tactile feedback is additional help that is not usually available when writing. It has been suggested that providing such additional feedback could be counter-productive at teaching a student how to carry out the skill autonomously. Feygin et al. (Feygin, Keehner et al. 2002) suggested that additional feedback may be more useful during the earlier stages of learning. This certainly seems to apply with McSig. The tactile feedback appeared to be very important for both May and Nikki as the students gained a basic awareness of shapes and learned how to write them. An additional learning curve is encountered later in the process where students learn how to write without the assistance of clear tactile feedback.

Students seemed to experience significant cognitive load during while signing a full signature. This is in agreement with the Cognitive Dimensions evaluation, which suggested that the task of learning to write would be characterised by the cognitive dimension *hard mental operations*. In Lessons 8 and 9, Nikki forgot which letter she was up to. May forgot which letter she was up to while writing the sequence “*umar*” in Lesson 8. The usual visual feedback was not available, which would show the student which letters have been completed. Instead, the student is required to remember which letter has just been done. A short lapse of attention could mean that the student forgets.

Nikki and May demonstrated a good level of retention, but Tim found it more difficult. Sometimes guiding the student through the letter with McSig would remind the student of the letter. For example, In Lesson 3 May was guided through the letter *r* once with McSig, and this prompted her to recall the letter. In Lesson 2, Nikki was reminded of how to do the letter *J*. Towards the end of the lessons, Nikki and May demonstrated great retention of the skills. In Lesson 9, May carried out an uppercase *M* and the letter sequence "*umar*" with no assistance. By Lesson 9, Nikki was also able to carry out the letters with no assistance. Tim struggled with retaining knowledge of the letters. In Lesson 9, he tried to remember letters by combining the directions up, down, left and right in seemingly random orders. Tim seemed to be less motivated to persist with learning the letter shapes. In Lesson 10 he was finding it difficult to remember *P*, *e*, *a* and *r*. He appeared to be lacking in concentration and patience. Tim's learning difficulties and problems with retention and recall seemed to be apparent here.

Tim's dependence on the memory technique caused problems for his learning. He used the directions up, down, left and right to summarise the shape of the letter. This caused problems for curved letters. For example, in Lesson 9, Tim seemed to be depending entirely on the "down, up, right, left" chant to remember an uppercase *P*. The curvature of the *P* was lost. Using these directions to prompt a student's memory could still be effective, as long as the student understands that the directions do not fully describe curvy parts of letters. In Lesson 6 with May the directions were used to prompt her through the letter *a*.

May was able to demonstrate significant spatial skills by the end of the lessons. During Lesson 10, she devised a new way to form an uppercase *K*. The starting position and direction of the strokes was different to the *K* taught in Lessons 5, 6 and 9. The resulting letter was correctly shaped like a *K*. This shows that the student was confident about her understanding of the shape of the letter. May also demonstrated spatial awareness by re-positioning her pen in Lesson 10 after a flick ended too close to the baseline.

7.2 Review of the McSig 2.0 System

Much can be learnt about the McSig system and the way students interact with it from the observations made during the study. The observations show how McSig can greatly assist visually impaired students in learning a signature. They also highlight ways in which the system could be improved to better support this task. A small number of changes were made to the implementation during the study, in response to observations. These are described in this section. Options for future improvements to the technology are also discussed.

A multimodal approach greatly assists the student's learning. The kinaesthetic, sound and tactile modalities combine to provide rich feedback for the students. The improvement shown by the students with letter formation demonstrates this.

7.2.1 Kinaesthetic Feedback

The haptic guidance helped to demonstrate spatial concepts that were difficult to describe verbally. In Lesson 9, the haptic guidance provided by McSig appeared to be greatly beneficial for Tim learning the complex curves of *e* and *a*.

Throughout the lessons, the teacher was able to use the blue-dot visual feedback to decide where to start a stroke. This meant that unexpected jerking movements of the student's pen could be avoided. In general, Nikki and May sought after clear tactile feedback keenly. They typically felt the markings that had been formed on the tactile sheet and positioned the pen tip where there was a clear space. Using the teacher feedback, the teacher was able to ensure that this start position was respected.

It is difficult to get a measure of how effective the pen-tip correction was. It was observed that the students frequently held the pen at a range of different angles. This means that more sophisticated pen-tip correction could be required. It appears that the device seems to lack the precision and forcefulness to make precise changes to the trajectory according to the tilt of the pen. The trajectory playback algorithm requires the pen to be moving a relatively large distance before a change caused by a change in pen-tip angle eventuates. It was also sometimes difficult to make small movements with the device when the student was holding the pen. However, the guidance is certainly sufficient for demonstrating larger movements and the general shape of letters.

One of the issues that needed to be overcome with the kinaesthetic feedback was teaching the student to hold the pen tightly enough. During Lesson 1, Tim held the pen loosely, so a portion of the lesson was spent focussing on this skill.

Sometimes the student would force the movement of the pen in a certain direction during teaching mode. This was not the intended way to use the system. It is, however, encouraging from the teaching perspective as it indicates that the student is gaining confidence with forming the letter shape independently. This happened during Lesson 5 and Lesson 6 with May. Tim also did this in Lesson 6. Such use of the system could potentially damage the motors of the PHANTOM device.

7.2.2 Sound Feedback

The students generally found the sound feedback engaging and interesting. Nikki was very interested in the sound, making comment on its musical qualities in Lesson 1. Nikki also brought her personal tape recorder and used it to record some of the sound feedback for various letters. Tim said in Lesson 1 that he liked the sounds.

The stereo pan options available in McSig 2.0 helped to provide useful stereo pan feedback. The default single letter mode was used for the vast majority of the time. While using this mode, the panning spans 25% of the width of the writing area. The signature mode was not needed until the students started to join all the letters together and form a signature. It was found that the custom versions of the single letter mode and signature mode were not frequently used. This is because the default width was a sensible size.

7.2.3 Tactile Feedback

As we expected from our work with Sue and the previous McSig study (Plimmer, Crossan et al. 2008), tactile feedback is extremely important to the users. This was apparent with May in Lesson 1. Both Nikki and May often spent time looking for un-marked space on the plastic during lessons, in an attempt to get clear tactile feedback for each letter attempt. Tim seemed to be less concerned with the tactile feedback (see Lesson 3).

Tactile rubber band lines were used with May in Lesson 4, Tim in Lesson 7 and Nikki in Lesson 4, 5 and 6. They were effective as a communication tool for explaining ideas such as lining up letters on the line and the relative height of upper and lowercase letters.

The tactile sheets are not sensitive enough. If too little pressure is applied, no marking will be formed on the sheet. This happened with Tim in Lesson 2 and to all of the students occasionally throughout the lessons. If the student over-compensates and applies too much pressure, the tip of the pen digs into the plastic sheet and the motors of the PHANTOM device are unable to move the student's pen, even if the software has instructed it to move. This was often observed during the study. This happened with Tim in Lesson 2 and May in Lesson 1. Nikki and May learned how to carefully apply a suitable level of pressure most of the time. This is a valuable learning exercise, as the students do need to learn about applying appropriate pen pressure with pen and paper. It would be preferable if the pressure that is needed with McSig is the same as the pressure required when using pen and paper.

A tactile surface which provided tactile feedback with relative ease would allow the student to concentrate further on the core task of learning letter shapes. A wax tablet was considered as an alternative tactile surface. A wax tablet with a flat surface could be placed on the writing surface in place of the dutch drawing board and plastic sheet. Wax which is sufficiently soft in consistency could be used to allow the student to more easily form marks on the tactile surface.

Hardware with a dynamic tactile surface may someday be able to provide more sophisticated support for tactile feedback. A requirement for a new tactile surface could include the ability to provide tactile feedback on a point or along a path in positive and negative relief. A further requirement could be the ability to provide feedback along a letter shape in a time-series. Constraint-based haptic guidance, where the user explores around a fixed letter shape, may be viable with such hardware. The original McSig study (Plimmer, Crossan et al. 2008) found that this did not work and suggested that it could be because there was no tactile feedback initially available for the non-writing hand. A new tactile surface could provide tactile feedback around a pre-defined letter shape.

During the longitudinal study, the students had to spend a lot of time looking for clear space on the plastic sheet. This was time-consuming and also used up plastic sheets. A dynamic tactile surface which supported erasability would solve this.

7.2.4 Screenshot Capture Tool

The screenshot capture tool greatly helped the flow of the lessons by automating screenshots with a single click. The keyboard shortcut Ctrl-S was also frequently used. The screenshot tool helped to support the complex task of playing the teacher and observer roles at the same time. The teacher was able to use this tool to make a note of the students' letter attempts that were particularly interesting. By saving the screenshot, the teacher implicitly notes that the example captured in the screenshot was important or relevant. This kind of information is not captured in the video records of lessons.

To keep screenshots from becoming cluttered, a modification was made to the screenshot tool during the course of the study, on July 21 (See Appendix 6). A problem was seen with obtaining clear screenshots of interesting attempts with Tim in Lesson 2. Multiple attempts carried out in quick succession would overlap, causing interesting examples to be lost. The teacher needed to repeatedly clear the screen using a keyboard shortcut, and ask the student to "stop writing for a moment" while a screenshot was taken. The screenshot tool was modified so that immediately following a screenshot, all the ink is cleared from the teacher's display automatically.

Annotation of the screenshots was also considered. One possible option would be to allow the teacher to type a relevant note in a text field. This was deemed too restrictive. The chosen option was for the teacher to write with the stylus in a blank space on the ink canvas. This annotation would be captured within the screenshot. The example screenshot in Figure 67 shows Nikki's attempt at a letter during Lesson 4. The strokes on the left are Nikki's. The text "pre P" is a teacher annotation. The “pre” here indicates that the letter has not yet been demonstrated with McSig. Annotations may be particularly useful in situations such as with May in Lesson 2, when the student was asked to form an *r*, yet she formed strokes resembling an *m*.

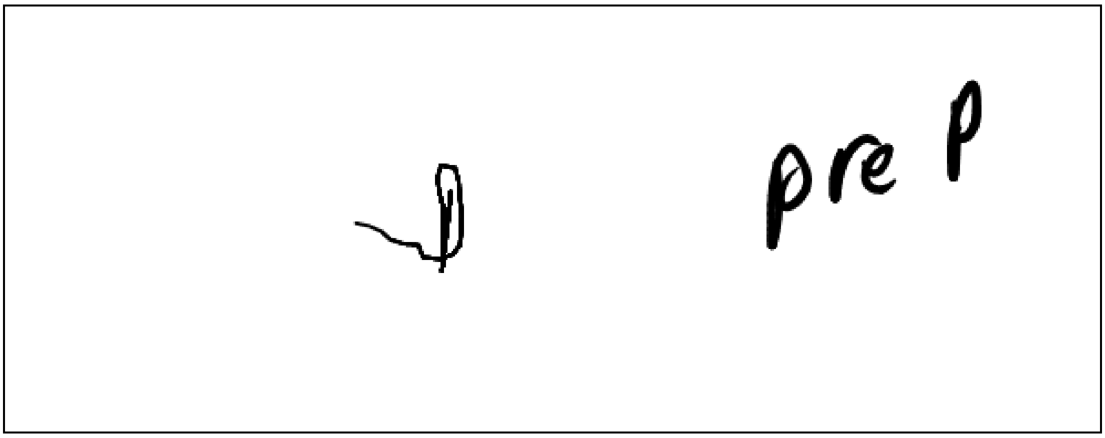


Figure 67 An annotated screenshot of a letter attempt by Nikki in Lesson 4.

During some lessons, it was relevant and important to observe where the student was beginning the letter stroke. For example, May’s attempt at an m began from the unconventional starting point in Lesson 1. Figure 17 has had a red dot added to indicate the starting point. The location of the start of a stroke can be obtained through the Microsoft Ink API on the Tablet PC. A valuable improvement to the screenshot tool could be to save a duplicate version of the screenshot with a red dot automatically added at the start of the stroke. This simple addition could automatically provide this extra insight without requiring unnecessary in-depth analysis of this aspect in video records of lessons.

7.2.5 Teaching and Freedraw Modes

Each student needed to be taught the role that he or she plays during the teaching and freedraw modes. The student’s role during the two modes is summarised in Table 3. In the teaching mode, the student is guided through the motion and plays a passive role. During freedraw mode, the student must apply effort to move the pen around the writing surface. During both the teaching and freedraw modes, the student must actively apply a force in the z dimension, pushing the PHANTOM pen down against the tactile sheet to form markings.

	x, y dimension	z dimension
Freedraw Mode	Active	Active
Teaching Mode	Passive	Active

Table 3. The student's role during freedraw and teaching modes

Further feedback could be provided to the students about which mode they are in. Switches between freedraw and teaching mode occur frequently. Each time the mode is changed, the teacher needs to communicate this to the student. This means that the teacher needs to say this a great number of times during a lesson. Each time, the student must concentrate carefully on what the teacher is saying regarding which mode they are now working in. Lessons require careful concentration and sometimes the student will not hear what the teacher has said. For example, In Lesson 5, Nikki needed to ask which mode we were in. The student said that she listened to what I was saying about which mode we were in.

One option could be to play an earcon when the mode is changed. A quick, distinctive musical sound has the potential to clearly and efficiently communicate the mode change to a student. Another possibility is to use kinaesthetic feedback in a similar manner. To indicate a mode change, the student's pen could be made to buzz or vibrate, similar to the vibrate functionality of a mobile phone.

The disadvantage of the two approaches mentioned above is that the information about which mode we are in is not continuously available to the student. This means that the student needs to remember which mode they are working in. A possible way to solve this problem could be to use a different character of sound feedback for letters shapes in the freedraw and teaching modes. However, this may prevent the student from being able to easily compare the sound feedback provided in freedraw and teaching modes. This could make it more difficult to use the sound to remember letters.

7.2.6 Pen-tip Height Sensing

The reliability of the pen-tip height sensing was improved on July 31 (See Appendix 6). Earlier in the study, the implementation of pen-tip sensing was clearly not robust enough when used by the students. On occasions when the pen tip was touching the writing surface, the software calculated its height as above the surface. Also when the pen was close to the surface but not touching it, it was sometimes calculated as being on the surface. Sometimes this resulted in the sound feedback erratically starting and stopping. Sometimes I turned off the sound during freedraw mode to prevent this from becoming a distraction to the student. The way in which the z coordinate of the pen tip was being calculated meant that the z coordinate was not consistent across all areas of the writing area. An offset was applied to the z coordinate depending on its position and an improvement in reliability was seen.

7.2.7 Ergonomics

Students were able to experience the benefit of having a pen more closely matched in size to a regular ballpoint pen. The students also had the ergonomic benefit of not needing to hold down a button during freedraw mode.

The cardboard template for angling the writing area was not used during the lessons. During earlier lessons, it seemed that as Sue had suggested, angling the writing area could confuse the students. Students generally seemed comfortable using the system for an entire lesson.

Tim and Nikki both had to spend time developing their technique for gripping the ballpoint pen. A suitable gripping technique involves the writing hand resting on the paper. This supports the hand so that letters can be formed in a controlled manner. Nikki had trouble forming smaller letters in Lesson 9 because of an undeveloped grip. Her improved pen gripping technique (see Figure 46) improved her control. During Lesson 9, Tim also learned how to better control the pen by improving his gripping technique. The shape of the PHANTOM pen and gimbal means that it is difficult to hold the PHANTOM pen in a similar way while using McSig. Alternative hardware may allow for a more thorough support for learning a good pen gripping technique earlier in the learning process.

7.3 Summary

The McSig system appears to greatly assist students to learn to sign a signature. Using McSig in combination with tactile aids such as pipe cleaners, students were able to gain an awareness of letter shapes and learn the motor skills needed to form them. The kinaesthetic feedback provided by the haptic guidance was capable of demonstrating spatial concepts that are difficult to explain verbally.

Throughout the learning process, the difficulty of the task is apparent. Writing a signature requires careful concentration. Students sometimes forget which letter they are up to and have little feedback to use to recover. This causes a reliance on the use of memory. Throughout the learning process, the students' reliance on tactile feedback is also made apparent. A learning curve is encountered when tactile feedback is removed.

At this stage we are beginning to see the limits of the equipment being used. The tactile sheet does not always produce clear tactile feedback. An active tactile surface could provide better feedback in this important modality. The pen on the haptic device is contrained more than a ballpoint pen. It is difficult to twist and move the pen naturally as one would with a ballpoint pen. Alternative hardware may allow students to rest their writing hand on the page and learn a more natural and controlled pen gripping technique earlier in the learning process. It is difficult to provide precise haptic guidance for small letters. Alternative hardware with the ability to more precisely position the pen tip may make it easier to teach the finer motor skills involved with forming small letters.

Chapter 8

Conclusions

McSig is a new, useful learning environment that can greatly assist visually impaired students learning a signature. The system uses an engaging multimodal approach to teach students the shapes of letters and the motor skills needed to form them.

An upgrade to the McSig 1.0 system offers more sophisticated support for the task of learning a signature. The requirements for the upgrade are informed by literature on teaching children to write, the McSig 1.0 study and our own observations of McSig 1.0. Requirements also arose from the need to prepare the system for a longitudinal study. The design of the new features was carried out in collaboration with a visually impaired adult. The upgraded system was evaluated using the Cognitive Dimensions framework.

A longitudinal study showed that the system appears to greatly assist students to learn a signature. Three visually impaired students were lead through 10 lessons each, with the goal of assisting each student to learn a signature. Nikki and May were able to make a substantial improvement in their ability to sign a signature. By the end of the lessons, both Nikki and May could form all of the letters in their signature along a baseline and incorporate cursive joins. Tim, who had learning difficulties, was able to effectively learn letters within lessons.

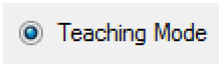
The longitudinal study revealed a lot about the McSig system. McSig particularly helps with developing motor skills. Limitations of the equipment are apparent. Alternative haptic hardware could allow the students to grip the pen more naturally and learn smaller, finer movements. The tactile modality is particularly important to the users. New tactile hardware could offer new opportunites. In the future, an active tactile surface would be an interesting extension to the system.

Some of the spatial concepts used in learning letter shapes and signatures are similar to those used in other types of learning. An area for future work is teaching geometrical and mathematical concepts to visually impaired students.

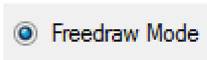
Appendix 1: McSig 2.0 Teacher View User Manual

Teaching Mode and Freedraw Mode

The two modes available are teaching mode and freedraw mode. During teaching mode, the teacher forms strokes on the Tablet PC, and the student's hand is guided around the movement by the PHANTOM. During the freedraw mode, the student moves the PHANTOM pen and ink appears on the teacher's software interface.

You can switch into teaching mode by clicking 

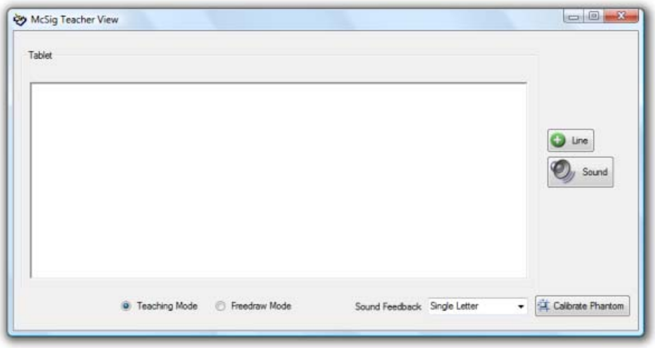
or using the keyboard shortcut Ctrl-T.

You can switch into freedraw mode by clicking 

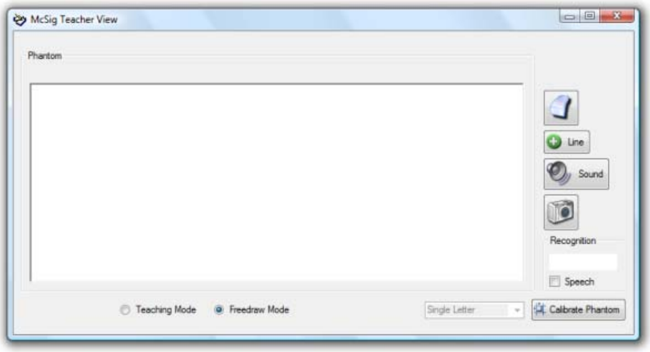
or using the keyboard shortcut Ctrl-F.

Different options are available in the two modes, as shown below.

Teaching Mode:



Freedraw Mode:



Sound Mute Toggle On/Off

The sound feedback can be toggled between on and off by clicking the sound button or using the keyboard shortcut Ctrl-Space.

Clicking the 

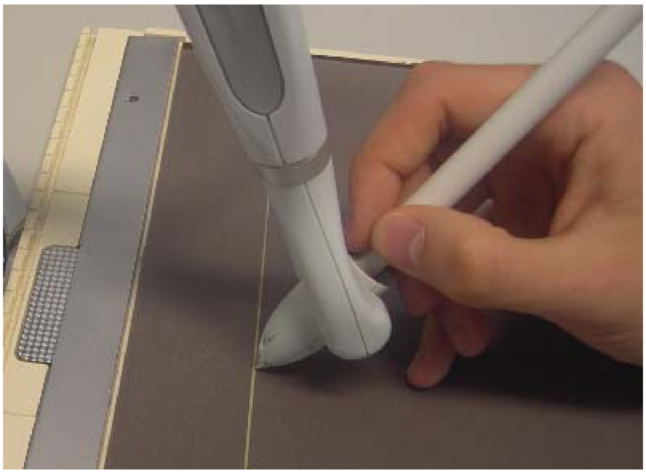
button will mute the sound. Clicking the 

button will turn the sound back on. By default the sound is on.

Add Line

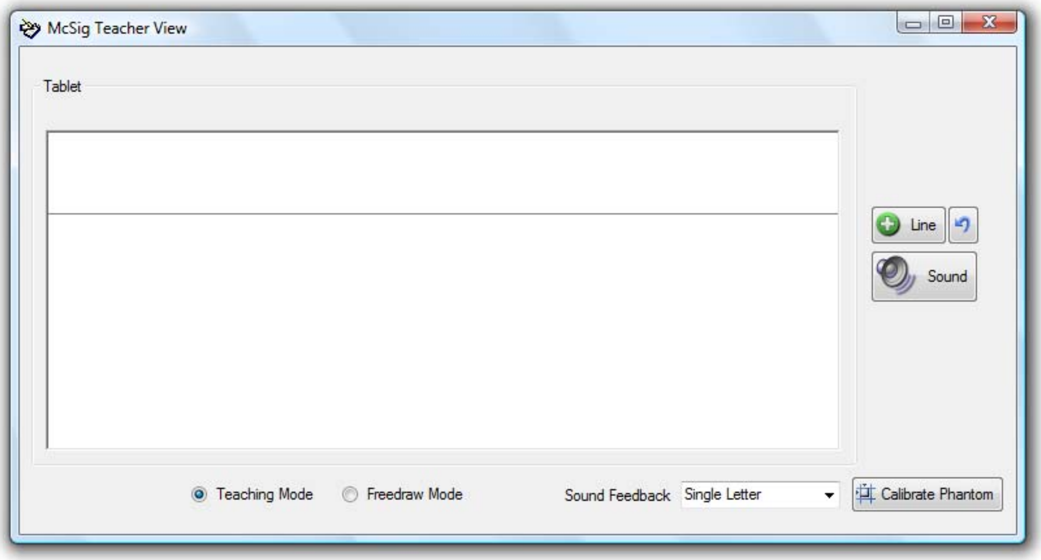
Rubber bands are used as tactile lines. Once a rubber band is placed on the Dutch drawing board, the teacher can add a line to their drawing area. To display calibrated lines to the teacher's software view, two steps must be carried out.

Step 1: Hold the pen tip on the rubber band as shown below.

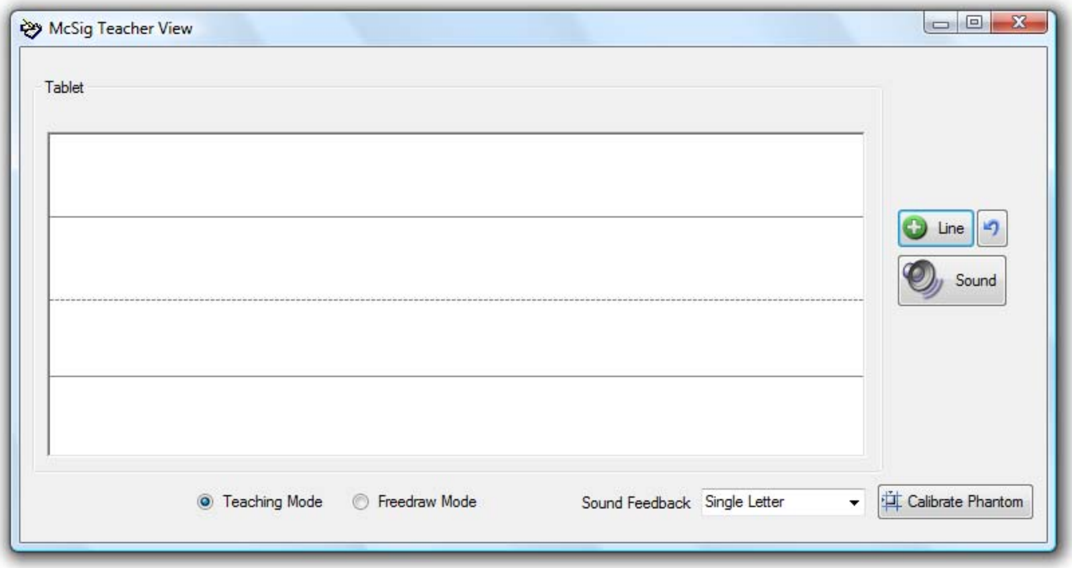


Step 2: Press the “Add Line” button  or use the keyboard shortcut Ctrl-L

A line will then appear on the screen as shown:

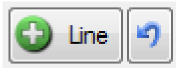


When three lines are added, the line which is in the middle is automatically rendered as a dotted line, since this line is less important.



Undo Add Line

Once a line is added, the undo button will appear next to the add line button. Press this button, or use the keyboard shortcut Ctrl-Z to remove the most recently added line. The undo button can be pressed repeatedly to remove several lines.



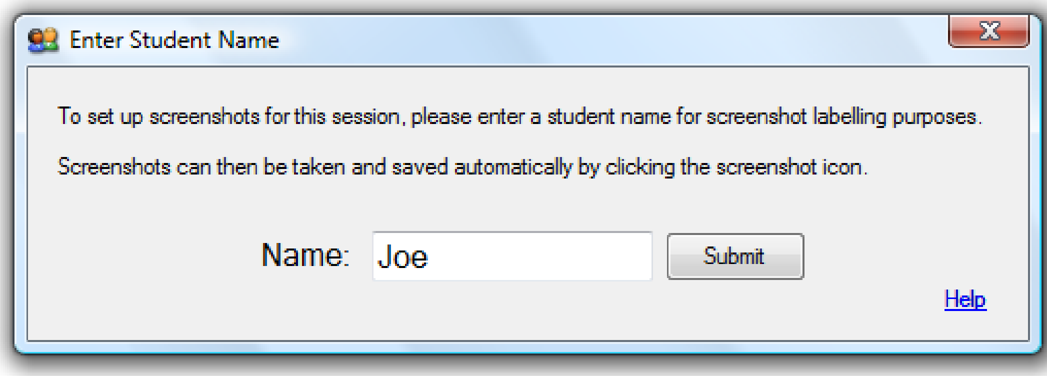
Clear the Drawing Canvas

In freedraw mode, to erase any ink marks from the drawing canvas, press the  button or use the keyboard shortcut Ctrl-X.

Take a Screenshot

In freedraw mode, you can take a screenshot by pressing the  button or using the keyboard shortcut Ctrl-S.

The first time that the screenshot button is pressed during a session, you will be prompted for the student's name. **Note**: no screenshot is saved the first time the button is pressed.



Every subsequent time that you press the screenshot button, a screenshot will be saved. Screenshots are saved in a folder called "Saved Screenshots" which is in the same location as the program executable.

Within this folder, the screenshots are further organized into subfolders which are labeled with the student's name, the day of the week and the date.

If the student name field is left blank, the screenshots for that session are saved in a "Screenshots" subfolder which is labeled with the day of the week and the date.

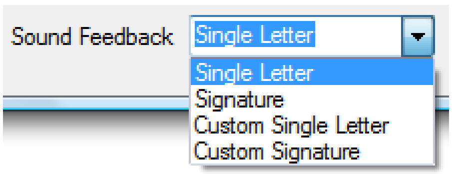
The screenshot button will briefly change to appear like this 

as the screenshot is taken and saved.

The drawing area is cleared immediately following a screenshot, to prevent the drawing area from becoming cluttered.

Sound Pan Feedback Options

There are two basic kinds of sound pan feedback. These are signature feedback and single letter feedback (see thesis for details). You can also create a custom version of each of these, to cater for strokes of varying width. You can select from among these four options using a drop-down menu.



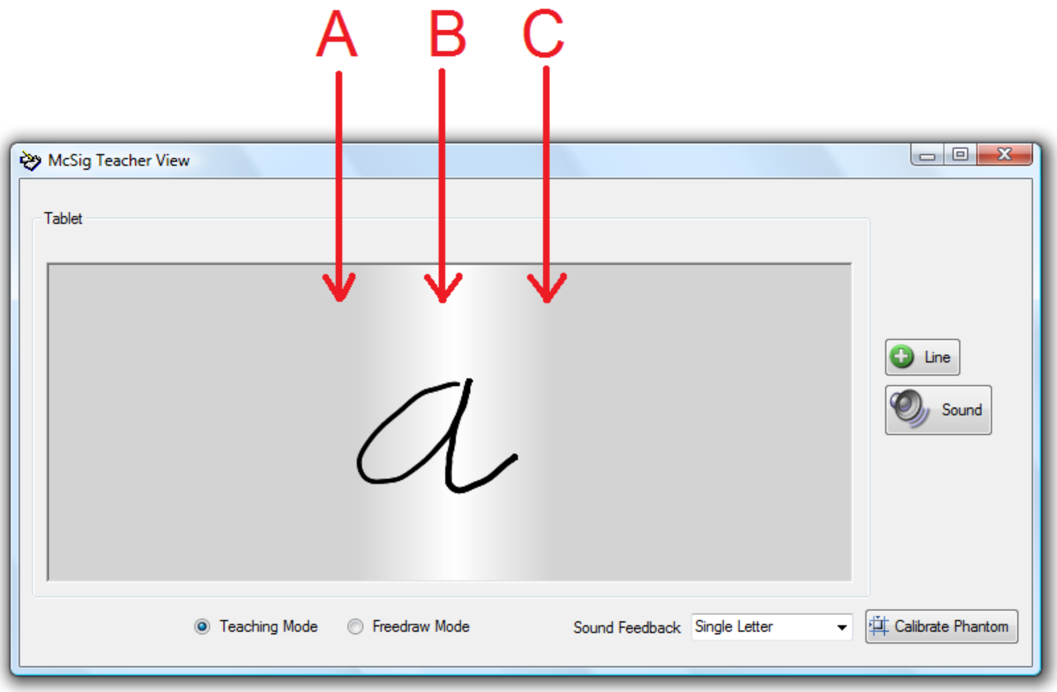
Keyboard shortcuts are provided for the default versions:
Single Letter Pan: Ctrl-Shift-S
Whole Signature Pan: Ctrl-Shift-W

Upon selecting one of the custom options, you will be requested to carry out an example stroke. The width of this stroke should be typical of the width of strokes you wish to carry out. The sound pan feedback is optimized for this width.

Stereo Pan Visualisation

When the pen hits the tablet screen, a visualisation is displayed to demonstrate how the stereo pan effect will behave. This visualisation is only shown when the sound is turned on.

In the figure below, A represents the position at which the sound will be panned fully to the left extreme. B is where the sound will be played through both speakers, which is the centre position for the pan. C shows where the sound is panned to the right extreme.



Position Correction Toggle On/Off

A correction can be carried out in order to adjust the position of the pen to account for the changing angle of the pen (see thesis for details). By default, the correction is on. To toggle the correction off and on, use the keyboard shortcut Ctrl-C.

Determining the Position of the Student's Pen

A blue dot will move around the writing area as the student's pen moves. This blue dot corresponds to the position of the student's pen.

Appendix 2: Participant Information Sheet – Parent or Guardian

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND
Te Whare Wānanga o Tāmaki Makaurau

Department of Computer Science
4th Floor, Building 303,
38 Princes St, Auckland
Private Bag 92019, Auckland
Phone (09) 373 7453

PARTICIPANT INFORMATION SHEET

Project title: *Computer Supported Non-Visual Drawing/Writing Training*
Researcher name: *Dr Beryl Plimmer*

To: Parent or Guardian

My name is Dr Beryl Plimmer I am a staff member at The University of Auckland conducting research into assistive technology to aid visually impaired children to learn to sign their names and draw geometric figures for maths. I am also the parent of a (now adult) blind child and remember her frustration with learning to write and sign. The goal of this project is to use computer-based technology to provide tactic and sound feedback to the children – making the task both more fulfilling and fun. I also remember the numerous requests that we received for my daughter to participate in research projects. In order to minimise the disruption and maximise the benefits to your child we have completed a two rounds of evaluations the first with visually impaired adults and teachers of the visually impaired and the second with a small group of visually impaired students. The results of these studies were very positive and we are now conducting a longitudinal study to explore learning retention and use of the same techniques for geometry. Your child has been selected to participate in this project by their teachers as learning these skills is a part of his/her current educational goals. Their experience as a visually impaired child will provide feedback to help us refine and improve the tool under evaluation. We also hope that the experience will be a positive learning experience for your child. If the information they provide is reported or published, this will be done in a way that does not identify them as its source.

The study will be conducted over several weeks and be designed to fit in with their other school work. Before the study we will give them time to explore (feel) the equipment and fully explain what is involved. They will work in conjunction with their teacher, me or my research assistant. A picture of the equipment setup is shown below. The teacher or researcher will be drawing and writing on the computer screen on the right of the picture. Your child will hold the pen attached to the robotic arm. The robotic arm echoes the teacher's movements to guide your child along the pen path. There are also pleasant sounds associated with the actions to affirm correct actions.

During the study we will observe their interaction, electronically record their interactions with the tool and video tape the session. The data collected will be stored in a locked filing cabinet in my office or a password protected electronic server for a period of up to six years as a reference for academic peer review of the project and as base-line data for further projects. At the end of this period the data will be destroyed by confidential document destruction.

The video and electronic recordings of the sessions are essential to allow us to later analyse technical problems with the tool and accurately assess its effectiveness. The analysis will be completed after the session by myself or my research assistant. The raw data will not be made available to any other parties – non-identifying composite statistics and descriptions will be shared with colleagues from Glasgow University, Scotland who working on the same technology and included in academic publications resulting from this study.

During study your child will be asked to complete some simple drawing and writing tasks using the robotic pen. The tasks and number of sessions will be determined in conjunction with your child and their child's teacher to best enhance your child's drawing/writing skills. Each session will take less than one hour. We do not anticipate that they will suffer any discomfort. However, you or they may withdraw consent and participation at any time during the study and their data for up to two weeks following each the session. You are welcome to observe the session and have a demonstration of the tool at the time of any session. Participation or non-participation will have no affect on your child's academic results.

Funding for this project has been provided by the University of Auckland Research committee.

Contact details	**Researcher**	**Head of Department**
	Dr Beryl Plimmer Department of Computer Science Ph 3737599 x 82285 Email beryl@cs.auckland.ac.nz	AProf Robert Amor Department of Computer Science Ph 373 7599 x 83068 trebor@cs.auckland.ac.nz

If you have any concerns of an ethical nature you can contact the Chair of the University of Auckland Human Participants Ethics Committee at 373-7599 extn. 87830.

APPROVED BY THE UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE ON 21 February 2007 for 3 years Reference Number 2006/441

Appendix 3: Participant Consent Form – Parent or Guardian

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND
Te Whare Wānanga o Tāmaki Makaurau

Department of Computer Science
4th Floor, Building 303,
38 Princes St, Auckland
Private Bag 92019, Auckland
Phone (09) 373 7453

PARTICIPANT CONSENT FORM (Parent or guardian)

Project title: *Computer Supported Non-Visual Drawing/Writing Training*
Researcher name: *Dr Beryl Plimmer*

From: Parent or Guardian

This consent form will be stored for six years and after that time will be destroyed by secure document destruction.

I have read the participant information sheet and I agree to have my child approached to take part in this research.

- I understand that my child will work with his/her teacher during the evaluation session
- I understand that the evaluation sessions will be observed, electronically recorded and videoed.
- I understand that this data will be held in locked filing cabinet or password protected electronic servers in Dr Plimmer's office for a period of up to six years as a reference for academic peer review of the project and as base-line data for further projects. At the end of this period the data will be destroyed by confidential document destruction.
- I understand that the data will be analyzed by Dr Plimmer or her research assistant.
- I understand that information provided may be reported or published, this will be done in a way that does not identify the individuals involved as its source.
- I understand that they may be reimbursed for local travel costs incurred by my child to attend the session up to a maximum of $40.
- I understand that I or my child am free to withdraw my consent for my child's participation in this research at anytime without giving a reason
- I understand that I or my child have the right to withdraw their information/data up to two weeks after the completion of each session.
- I undertake that their participation or non-participation will have no impact on my child's academic results.
- I understand that I may observe the evaluation sessions and request to have the tool demonstrated to me.

Name of child ________________________

Name ________________________

Signature ________________________

Date ________________________

Contact details	**Researcher**	**Head of Department**
	Dr Beryl Plimmer Department of Computer Science Ph 3737599 x 82285 Email beryl@cs.auckland.ac.nz	AProf Robert Amor Department of Computer Science Ph 373 7599 x 83068 trebor@cs.auckland.ac.nz

If you have any concerns of an ethical nature you can contact the Chair of the University of Auckland Human Participants Ethics Committee at 373-7599 extn. 87830.

APPROVED BY THE UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE ON 21 February 2007 for 3 years Reference Number 2006/441

Appendix 4: Participant Information Sheet – Child Participant

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND
Te Whare Wānanga o Tāmaki Makaurau

Department of Computer Science
4th Floor, Building 303,
38 Princes St, Auckland
Private Bag 92019, Auckland
Phone (09) 373 7453

PARTICIPANT INFORMATION SHEET

Project title: *Computer Supported Non-Visual Signature Training*
Researcher name: *Dr Beryl Plimmer*

To: Child Participant

My name is Dr Beryl Plimmer I am a staff member at The University of Auckland conducting research into assistive technology to aid visually impaired children to learn to sign their names and draw geometric figures. I am also the parent of a (now adult) blind daughter and remember her frustration with learning to write and sign. The goal of this project is to use computer-based technology to provide tactic and sound feedback to you. In an earlier study visually impaired children showed significant improvements in their writing in one 20 minute session. We are now trying to find out how effective this equipment is over a number of sessions. I wish to invite you to participate in this project as your experience will help us refine and improve the tool. We also hope that the experience will be a positive learning experience for you. If the information you provide is reported or published, this will be done in a way that does not identify you as its source.

Before the study we will give you time to explore (feel) the equipment and fully explain what is involved. You will work in conjunction with your teacher. Your teacher, me or my assistant will be drawing and writing on the computer screen while you hold the pen attached to the robotic arm. The robotic arm echoes our movements with the pen on the computer screen to guide you along the pen path. There are also pleasant sounds associated with the actions.

During the study we will observe your interaction, electronically record your interactions with the tool and video tape the session, ask you what would be helpful to you and answer any questions you may have. All the data collected will be stored in a locked filing cabinet in my office or password secured electronic server for a period of up to six years as a reference for academic peer review of the project and as base-line data for further projects. At the end of this period the data will be destroyed by confidential document destruction.

The video and electronic recordings of the sessions are essential to allow us to later analyse technical problems with the tool and accurately assess its effectiveness. The analysis will be completed after the session by me or my research assistant. The raw data will not be made available to any other parties – non-identifying composite statistics and descriptions will be shared with colleagues from Glasgow University, Scotland who working on the same technology and included in academic publications resulting from this study.

In this study you will be asked to complete some simple drawing and writing tasks using the robotic pen. We will track your progress so that the tasks, timing and number of sessions can be agreed between us to fit in with your current educational goals. The session will take less than one hour. We do not anticipate that you will suffer any discomfort. However you may withdraw consent and participation at any time during the session and your data for up to two weeks following the session. Your participation or non-participation will have no affect on your academic results.

Funding for this project has been provided by the University of Auckland Research committee.

Contact details	**Researcher**	**Head of Department**
	Dr Beryl Plimmer Department of Computer Science	AProf Robert Amor Department of Computer Science Ph 373 7599 x 83068

	Ph 3737599 x 82285 Email beryl@cs.auckland.ac.nz	trebor@cs.auckland.ac.nz

If you have any concerns of an ethical nature you can contact the Chair of the University of Auckland Human Participants Ethics Committee at 373-7599 extn. 87830.

APPROVED BY THE UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE ON 21 February 2007 for 3 years Reference Number 2006/441

Appendix 5: Participant Consent Form – Child Participant

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND
Te Whare Wānanga o Tāmaki Makaurau

Department of Computer Science
4th Floor, Building 303,
38 Princes St, Auckland
Private Bag 92019, Auckland
Phone (09) 373 7453

PARTICIPANT CONSENT FORM (Child)

Project title: *Computer Supported Non-Visual Drawing/Writing Training*
Researcher name: *Dr Beryl Plimmer*

To: Child Participant

This consent form will be stored for six years and after that time will be destroyed by secure document destruction.

I have read the participant information sheet (or had it read and explained to me) and I agree to take part in this research.

- I understand that the evaluation sessions will be observed, electronically recorded and videoed.
- I understand that this data will be held in locked filing cabinet in Dr Plimmer's office or password protected electronic servers for a period of up to six years as a reference for academic peer review of the project and as base-line data for further projects. At the end of this period the data will be destroyed by confidential document destruction.
- I understand that the data will be analyzed by Dr Plimmer or her research assistant.
- I understand that information I provide may be reported or published, this will be done in a way that does not identify me as its source.
- I understand that I am free to withdraw from the research at anytime without giving a reason
- I understand that I have the right to withdraw my information/data up to two weeks after the completion of each session.
- I understand that my parents or guardians have also given their consent to my participation in this study and that they too have the right two withdraw consent for my participation or data on the same terms as I do.

Name ________________________

Signature ________________________

Date ________________________

Contact details	**Researcher**	**Head of Department**
	Dr Beryl Plimmer Department of Computer Science Ph 3737599 x 82285 Email beryl@cs.auckland.ac.nz	AProf Robert Amor Department of Computer Science Ph 373 7599 x 83068 trebor@cs.auckland.ac.nz

If you have any concerns of an ethical nature you can contact the Chair of the University of Auckland Human Participants Ethics Committee at 373-7599 extn. 87830.

APPROVED BY THE UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE ON 21 February 2007 for 3 years Reference Number 2006/441

Appendix 6: Lesson Calendar and Date of Implementation Changes

The table below shows the dates when lessons were carried out with each of the three participants. The dates when changes were made to the implementation are also indicated.

	Tim	May	Nikki	
July 16	Lesson 1			
17				
18	Lesson 2			
19				
20				
21				← Changes 1*
22	Lesson 3	Lesson 1		
23				
24		Lesson 2		
25				
26				
27				
28				
29				
30				
31				← Changes 2*
August 1				
2				
3				
4				
5				
6				
7	Lesson 4		Lesson 1	
8				
9				
10				
11			Lesson 2	
12		Lesson 3		
13		Lesson 4		
14	Lesson 5		Lesson 3	
15				
16				
17				
18			Lesson 4	
19				
20				
21				
22				
23				
24				
25				
26		Lesson 5		

27			
28	Lesson 6		
29			
30			
31			
October 1			Lesson 5
2		Lesson 6	
3			
4	Lesson 7		Lesson 6
5			
6			
7			
8			Lesson 7
9			
10			
11			
12			
13			
14			
15			Lesson 8
16		Lesson 7	
17		Lesson 8	
18	Lesson 8		Lesson 9
19			
20	Lesson 9		
21			
22			
23			
24		Lesson 9	
25	Lesson 10	Lesson 10	Lesson 10

***Changes 1**: To make collecting screenshots easier, the screenshot tool was altered so that the ink canvas is cleared after each screenshot. This prevents screenshots from becoming cluttered. It was also decided that the teacher could annotate screenshots by writing with the stylus on the ink canvas.

Changes 2: The accuracy of the pen-tip height sensing was improved.

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