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Multimodal collaboration environment for inclusion of visually impaired children

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Summary

This report describes a pilot evaluation in three parts, of collaboration in multimodal interfaces performed in the MICOLE project, Work Package 3 (Task 3.4). The studies have been conducted in three different countries (Sweden, Scotland and Finland) by five partners (UGLAS, METZ, ULUND, UTA and KTH).

The aim of Task 3.4 was to conduct pilot evaluation studies of collaboration in multimodal environments between sighted and visually impaired pupils in schools. These pilot evaluation studies aim at investigating if the design of the applications that are implemented in the final MICOLE system fulfils the usability requirements and the needs of the user group in the real context that is group work in schools.

In this report, three evaluations of the three collaborative applications that were decided to be included in the final system are presented. These three applications are the Drawing application, the Electrical circuit and the Space application.

The evaluations that are presented in this report have resulted in recommendations for improvements of the applications and also recommendations regarding methodology that can be used in the final evaluation of the system.

1. Introduction

The MICOLE project is aimed at developing a multimodal system that supports collaboration, data exploration and communication for visually impaired children and their peers as well as their teachers. In the MICOLE project multimodal interaction technology is developed based on the needs and abilities of visually impaired users in order to support collaboration. These multimodal tools will support different senses that more or less can replace missing visual capabilities.

In face-to-face communication and collaboration people are used to being able to both see and hear other persons. People also take for granted the possibility to give objects to each other, to shake hands or to get someone's attention by a pat on the shoulder. Because social skills are in general becoming increasingly important in society, it is important to support learning through social interaction also for visually impaired pupils. Historically, and chiefly due to technological limitations, haptic feedback and auditory displays have appeared relatively infrequently in studies of mediated communication and collaboration. Recent advances have begun to overcome these restrictions, and there is an urgent need to investigate the effects of combining these modalities in order to support group work including visually impaired pupils in school.

The integration of audio and haptic input and output techniques can increase the bandwidth for information exchange for both sighted and blind and can provide a shared representation of a group work task. It has been shown that the specific characteristics of any particular perceptual task should be considered, in relation to the specific properties of the sensory modality (modalities) that provides information for performance of the task (Heller & Schiff, 1991). Furthermore, the sensory modalities are specialised for different tasks, and that specialisation emerges more strongly as the complexity of the task increases. If only haptic and auditive information can be conveyed in a collaborative interface the fact that the visual cues cannot be used is a difficult challenge to overcome. But we argue that a shared interface that can be useful for both blind and sighted can be accomplished through good design.

We have shown in several studies in this project, that a shared understanding of the workspace and the objects in it can be achieved between blind and sighted pupils (Sallnäs et al, 2006; Fredrik, 2006). Results show that a shared work process can be obtained in these types of multimodal interfaces, by which visually impaired pupils through teamwork with their sighted fellows can form an understanding of the workspace layout. It is possible to achieve a common ground and to discuss a task like for example a math problem together when all group members can explore the same workspace with different senses. The shared interface makes possible a problem-solving process where everyone is included. However, the design of the multimodal environment affects the level of inclusion in a powerful yet subtle way, which makes it very important to carefully design both the visual, haptic and sound cues in it in order to get a truly inclusive environment.

Problems for example occur if objects can be moved around in a collaborative environment and the interface does not give awareness cues about changes that takes place due to the movement of objects by many people. The coordination then gets more complex for the visually impaired pupils because they cannot keep track of all the changes in the environment. Some additional support is therefore needed like for example sound cues in order for the impaired pupil to be aware of changes. However, the combined navigation and object handling like lifting and moving objects seems though not to be a problem in haptic environments.

Another general result that has been found in our previous studies in this project is that the pupils use the haptic navigational guidance functions as well as verbal guiding to a large extent in order to refer to objects and procedures. This can be used in many ways. One way is to lift an object together in a certain direction and thus guide one another at the same time as decisions are made about how to solve the problem (Sallnäs et al, 2006). Another example is that one person can show the shape of a picture and another person can be guided along that path (Crossan and Brewster, submitted). Finally a dragging function can move one pupil to the other pupil's location so that they both can discuss that specific part of the workspace like for example a section of a building (Oakley et al, 2001).

A social protocol has been found to develop around the use of these guiding functions that has to do with how to use it in a respectful way. It has also been found that the design of these functions affects the usefulness a great deal. For example a "shape-showing" function is best designed as a full control real-time movement of both users in order for them to be able to discuss the different parts of the shape as they are moving the cursors. This is by the way a very fine example of how awareness of the activity supports common ground and joint problem solving. Results also indicate that it is advisable to always give all parties in a collaborative situation the same possibilities to “drag” someone to ones own location in order to accomplish a truly inclusive work situation.

Cross-modal collaboration between blind and sighted users has been studied within the project as well (Winberg & Bowers, 2004, Winberg, 2006). Cross-modal collaboration involves collaboration between two or more parties where the interaction with the shared data is made through different modalities. In the study by Winberg and Bowers (2004), no overlap in modalities existed, the sighted subject could not hear what the blind subject heard, and naturally the blind subject could not see what the sighted subject saw. In this study, special attention was put on observing turn taking, awareness, communication, and error recovery. Also, here a shared work-space is accomplished but with no access to the other persons

One specific issue that has been addressed in Task 3.4 this year is perception of tactile diagrams by visually impaired users is a complex task. This work attempts to study techniques for improving these processes by combining force and tactile feedback. The aim was to develop a system that provided similar information to blind and sighted users through haptic and visual presentation respectively to allow two users to collaborate, to build up a mental representation of a circuit and to solve a task together. For the evaluation in Task 3.4 the Electrical circuit application was further developed so that a VTPlayer mouse and a Phantom could be used simultaneously in the system in a collaborative setting.

Another perspective that has been investigated in Task 3.4 is collaborative use of a multimodal drawing surface in which a teacher could prepare a group work task for a group including visually impaired and sighted pupils. In this application visually impaired pupils could create and access graphical images via haptic and auditive feedback as well as visual feedback for sighted users. The application was further developed for this evaluation in such a way that a sighted pupil could use an ordinary mouse in order to activate sound cues and drag the visually impaired user to a specific location. The visually impaired pupil used a Phantom in order to feel the shape of the drawing and also to activate the sound cues. When dragged, the visually impaired user was physically moved via the phantom arm to the location that corresponded with the one the sighted were in. In the pilot evaluation the pupils engaged in a collaborative task that involved exploring of graphical images of the Shakespearean Globe Theatre. The teacher who was responsible for the pupils that participated in the evaluation planned this task that was a rather complex task.

Finally, one aim in Task 3.4 was to investigate how the Space application with one Phantom device is suited for visually impaired and sighted pupil’s collaborative exploration. The application was originally designed for one user at a time and in this phase no new characteristics for collaboration support was implemented but a collaborative setting was investigated with this application. Two children at a time was sitting in front of the phantom device and their behaviour was video-recorded when using the Space Application. Testing took place in May 2006 and the initial analysis was done in June 2006. The second analysis has been made in January 2007 and in this second much more detailed analysis the focus has exclusively been on those parts of testing procedure where children are resolving the tasks given to them by the test assistant.

1.2 Objectives of the work package

The objective of MICOLE Work Package 3 is to investigate the specific issues of collaboration in cross-modal interfaces in order to gain knowledge about how visually impaired and sighted children can interact and learn on equal grounds. Another objective of this Work Package is to make a mapping of problems in interaction between sighted and visually impaired children in collaborative situations in their environment in the field.

In this third year, these objectives were addressed in Task 3.4 (Feasibility study in the field). The aim in this Task 3.4 is to study an initial version of the applications, designed and implemented in WP4, in a real learning environment and to evaluate if visually impaired and sighted children can get added value from using it in their interaction with peers. In order to achieve this in Task 3.4, pilot studies of collaboration in multimodal environments between sighted and visually impaired persons were conducted in three countries (Sweden, Finland and Scotland) jointly by five partners (ULUND, UGLAS, METZ, UTA and KTH). These pilot studies aimed at developing the applications that were included in the final MICOLE system so that they support a collaborative setting. Furthermore, the aim was to develop the methodology for studying collaboration in group work further, before the final evaluation of the final MICOLE system. One more aim of this Task 3.4 was to validate our results from the previous year about how to design collaborative multimodal systems for group work including visually impaired and sighted pupils.

Royal Institute of Technology, KTH has been co-ordinating the work that was done in order to get the pilot studies started at the different locations. Researchers at KTH have arranged work meetings with the different partners that have been involved in task 3.4 in order to plan and design pilot evaluation studies of collaboration between sighted and blind persons.

It is important to point out that doing the work in Task 3.4 has been a truly joint effort that was realized by people working together in projects across partner sites in Europe. UGLAS worked very close with METZ in order to design and perform the evaluation of the Electrical circuit application in Scotland. ULUND and KTH designed and conducted the evaluation of the Drawing application together in Lund, and KTH and UTA designed and did an evaluation of the Space system together in Tampere. This has proven to be very valuable, as all partners involved have been forced to consider many new perspectives. This has helped us in developing the system and the way partners conceive of the research questions posed in the MICOLE project.

2. Joint Exploration of Electrical Circuits

This section describes an initial collaborative evaluation of the accessible electrical circuits application developed by METZ. A pilot study conducted by UGLAS evaluating this environment is described here with two groups of participants collaborating on exploring a series of circuits using the interface.

2.1 Background information

The goal of this work is to create a collaborative multimodal training environment for visually impaired children. In this context, a study was carried out concerning the needs of 7 visually impaired children and 25 teachers. This study revealed important problems concerning the teaching of diagrams like the electric circuit diagrams, geographical charts and mathematics. In effect, the children have difficulties exploring a diagram without the assistance of a teacher. Moreover they find it difficult to use and understand diagram legends, and to understand local and global information in the diagram. We were therefore interested in creating an environment to allow exploration of diagrams. We chose to focus on electric circuit diagrams because the separation of both local information and the global overview is natural. Exploration of the full circuit and obtaining an overview corresponds to the form of the circuit: for example the concept of series/parallel. Local exploration concerns the recognition of the polarized components comprising the circuit.

One notable related project is TeDub (Horstmann et al., 2004), which is again looking to provide a system to produce accessible technical diagrams. This system attempts to read in information in the form of an image or XML file, automatically processes and produces a document that can be accessed though speech, sound and touch.

2.1.2 Tactile diagrams

Traditional methods of accessing diagrams use raised paper, which raises certain parts of the image to allow users to explore shapes or lines presented through tactile relief. Providing accessible tactile diagrams through this method is not a trivial task however. Many authors have noted that a direct translation of a visual diagram to a tactile diagram is not always sufficient to provide accessible tactile diagrams (for examples see (Challis & Edwards, 2001), (Kurze, 1996), and (Crossan & Brewster, 2006)).

There have, however, been a number of attempts at addressing the problem of accessibility of tactile diagrams. It is important to ensure that any system developed to build or explore tactile diagrams addresses the important issues that arise that are specific to presenting diagrams through touch. Eriksson (1999) describes several principles that are important when presenting a blind or visually impaired person with a tactile picture. One key feature emphasised by Eriksson is ensuring that a textual description is available. This is important both for an overview of the image as a whole and a more detailed description of the individual components that make up the image. It is also important to ensure that users can build up a spatial representation of the image by allowing them to explore the relative positions of objects within the image.

While these diagrams provide an invaluable tool for allowing visually impaired people to browse non-textual information such as diagrams or charts, they suffer a number of disadvantages. They are static representations that it is difficult to add to or remove from without reprinting the image. They rely solely on tactile relief to present information and cannot take advantage of any computer-based technologies such as screen readers or tactile devices to aid comprehension. As such, a number of attempts to provide computer based or hybrid alternatives to raised paper have been investigated.

Bliss et al. (1970) describe an early commercially available device that was designed to make printed information accessible to visually impaired people by combining a camera and vibrotactile array. The user moved the camera over a document with his or her dominant hand. The printed information was then displayed to the user's non-dominant hand through a vibrotactile pin array with the dark areas of the document represented as vibrating pins and the light areas as stationary pins.

Kurze (1996) describes a drawing environment that combines swell paper – to create a physical line based representation of the drawing – with a stylus and digitiser to provide positional information to a computer within an image. Verbal cues are used to label different lines on the image which can subsequently be read back by the computer as the user explores the drawing. Landua & Wells (2003) similarly describe the Talking Tactile Table, a hybrid system which combines a raised paper representation with a touch sensitive tablet for making diagrams accessible. Users can explore the raised paper representation as normal, but can also press down on an area of interest and hear information through speech about that particular area of the image. By using different pre-created raised paper diagrams that the Tablet system can distinguish, context sensitive speech information can be given to the user for multiple diagrams.

Wall & Brewster (2006) present a computer-based system for accessing bar charts that shares many features with a raised paper diagram. The user navigates the image by moving a stylus over a graphics tablet representing the physical piece of raised paper. The user's non-dominant hand rests on a raised pin tactile display that provides a simple binary up/down signal to the user for the area around the user's cursor depending on whether they are above a dark area of the screen or a light area. One immediate advantage of this system over a traditional raised paper representation is that it is computer-based. Charts can easily and quickly be reloaded. The system can take advantage of the computer-based representation to track the user's movements and provide further feedback to aid the user to navigate the environment. McGookin & Brewster (2006) describe a system that allows a user to explore a bar graph felt in negative relief through force-feedback. One novel feature here was the incorporation of multiple views of the same information that could be browsed in different manners for different purposes. A direct translation of the visual representation was presented to allow a common frame of reference for exploring and discussing with a colleague with a visual representation or the same graph. An easy to browse 'sound bar' was also presented that allowed the user to get a quick overview of the data values through non-speech audio by running the cursor over the base of the graph.

2.2 Application evaluated

2.2.1 Description

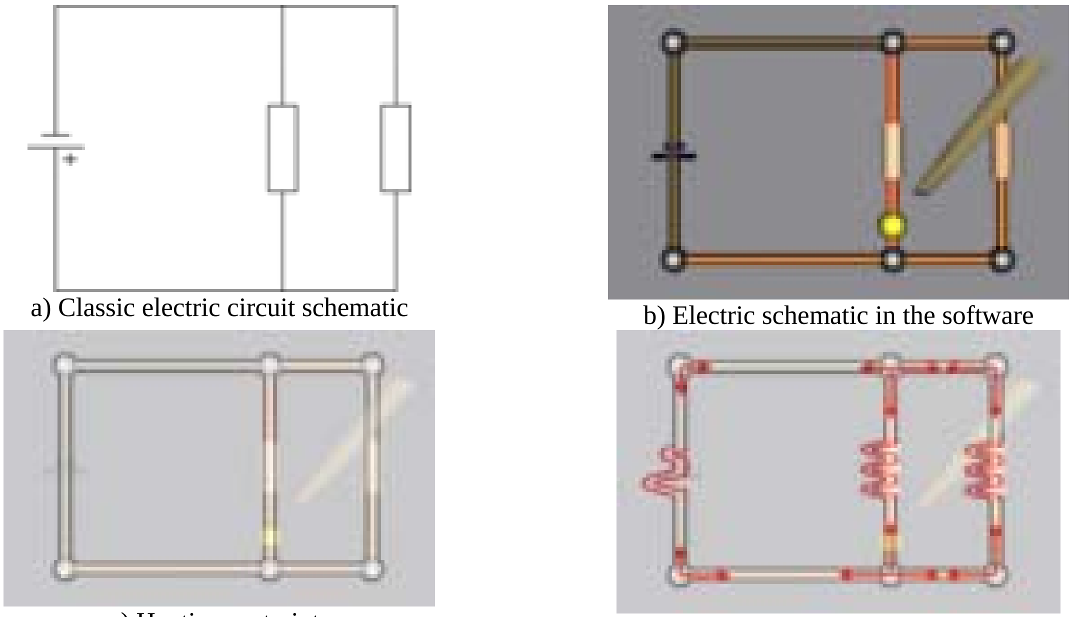
The haptic electrical circuit exploration software aims at providing the user a multilevel exploration system for visually impaired children. It means that all the electrical circuit features that can be usually understood by vision must be understandable by haptics. In particular the user should have the possibility to get an overview of the circuit's global shape, and should be able to recognize local parts like components.

We developed the software such that the PHANToM's stylus-tip is trapped inside the virtual circuit. When the scene is loaded, the user is automatically guided to a predefined position that the user could use as a reference point. Moreover we decided to put the circuit on a horizontal plane such as the users feel like drawing on a table.

2.2.2 Interaction techniques

The user is constrained into the circuit so he can feel its shape. In order to help him navigating into it we included some directional cues. We placed some haptic impulsions at the intersections: the user is dragged on several millimetres to show him where he can go. This interaction is what we called "Guided PICOB (PICOBg) interaction" that is guided bumps where the 3D device completely controls the movement. These cues are only played when the user asks for help, because according to our studies users prefer exploring by themselves and only ask for help when they want it. We use two bump amplitudes so that we encode already explored directions with little bumps, and not explored yet direction with big bumps. The goal is to let the user know if he has already explored the whole circuit.

The electrical components are felt in another way: while the user is exploring a wire on the circuit, he will feel some bumps that indicate there is a component. This is a "Half-guided PICOB interaction" (PICOBhg) that is bumps where the 3D device only constrains the user on a path. The components are coded with bumps sequences which direction can be up or down and size can be big or small. For example three big up means a resistor, and one big up plus one small up means a battery. We display the components on the VTPlayer too: we designed an icon for each component. We use crossmodality to give the user several ways to understand the information. Some user may prefer the force-feedback interaction, others may prefer this tactile interaction.



a) Classic electric circuit schematic
b) Electric schematic in the software
c) Haptic constraints
d) PICOB : guided and half-guided

Figure 1. The electric circuits environment. a) shows the schematic of a circuit, b) show a screenshot of that circuit in the environment, c) shows the aceas that the user is constrained to in the circuit, and d) shows a representation of the haptic bumps felk through the Phantom when going over components.

The tactile feedback in this instance is displayed through one 4 x 4 array of pins in the VTPlayer tactile mouse. The tactile symbols used for each component are shown in Figure 2. These tactile symbols remained the same no matter what orientation the symbol on the diagram was. They were presented as soon as the user moved onto a wire containing the component (or the node symbol when on a junction) and were shown for the whole length of the wire, not just when the user's cursor was directly over the component. A similar form of tactile feedback has been examined by both UGLAS (Crossan & Brewster, 2006) and METZ (Pietrzak et al., 2006).

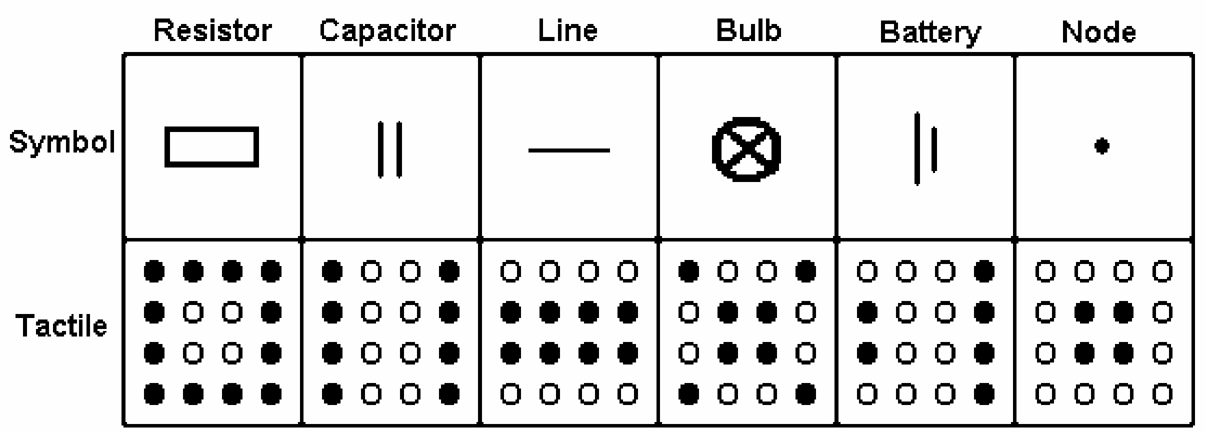


Figure 2. The symbolic and tactile representations for each symbol in the environment. In this instance, a black circle represents a feelable pin.

2.3 Evaluation methodology

A pilot study was conducted in order to firstly evaluate the potential of this tool as a collaborative learning environment for sighted and blind people, and secondly to inform the design of a future evaluation with visually impaired children.

2.3.1 Participants

An initial pilot investigation was carried out with two pairs of users. For each of the pairs one user was blind and the other sighted. One user in each group was familiar with circuits and one had no recent experience of circuits. In this instance, it was the visually impaired user in both groups who had more experience with circuits. In the first pair (P1), the visually impaired user was under 50 years old and had good vision until ten years ago. He had studied electronics to second year university level when younger. The sighted user was a Masters student at University of Glasgow who had no recent experience of electronics.

For the second pair of users (P2), the visually impaired user had been blind since birth. He gained a degree in electronics using tactile diagrams to interpret the circuits when required. Further to this, he has previously been involved in testing novel more sophisticated tactile diagrams displaying circuits. The sighted user had experience of circuits from physics at school level, but no recent exposure to the subject and claimed to remember very little.

Both visually impaired users had previous but not recent exposure to the Phantom and VTPlayer mouse.

2.3.2 Task

The task set for each pair was to collaborate with their partner to understand five circuits of varying complexity such that both users were able to describe the circuit and how it worked. The components used in the study are shown in Figure 2. The five circuits used in the study are shown in Figure 3. The circuit designs were chosen by the experimenter to demonstrate the key aspects of simple electrical circuits that might be experienced by school children.

The visually impaired user could interact with the Phantom with his or her dominant hand to explore the circuit. The current Phantom position was shown visually on the monitor allowing the sighted user to keep track of the visually impaired user's movements. The visually impaired user also felt tactile cues presented through the VTPlayer mouse to the index finger of the non-dominant hand. The sighted user could view the circuit on the monitor along with the current position of the visually impaired user's cursor. They were also informed that they could physically move their partners' cursors by moving the Phantom arm that the visually impaired users held.

Before the experiment started, the visually impaired user was allowed to feel the different symbols for each component and was told what they represented. In order to initiate collaboration, the sighted user – who could very quickly gain an overview of the circuit through a visual glance – was not told what each of the component symbols in the circuit represented. The visually impaired users were informed that they would need to communicate to their partners which component was which.

Video and audio recording of the participants performing the task were taken. *Post hoc* analysis of user interactions was used to determine what techniques were used to allow the users to perform the task collaboratively.

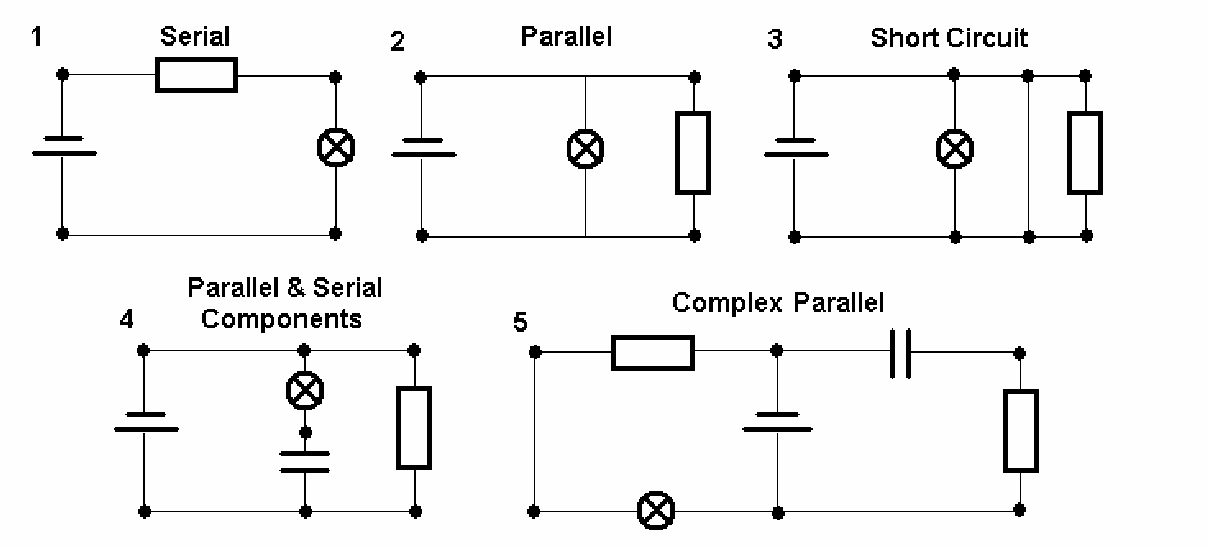


Figure 3. The five circuits used for this experiment. The different components and their corresponding symbolic representations are shown in Figure 2.

2.4 Initial observations

Both groups of users completed the task successfully. Taking a mean of approximately 4 minutes per circuit for P1 and 2 minutes per circuit for P2. In all instances, the visually impaired users were able to identify all components in the circuit and placed them in the correct positions within the circuit. The visually impaired user was able to provide information to the sighted user mainly through reference to the current cursor position within the environment. This was initial helpful in identifying components. For example, for the visually impaired user (VI) and sighted user (S) in P1.

S: Which one is the battery ?
VI: The battery is a short line and a long line.
S: So you're on a line. What's that there that you're going through now ?
VI: That's the battery.
S: OK. Yes.

It also proved useful in allowing the sighted user to both direct the blind user along a path and make them aware of other potential paths to traverse. For example, after starting in the middle and traversing the left half of circuit 3 in Figure 3:

VI: Junction. So that means I guess that I'm back vertically to just below where I started.
S: Yes. In the middle so there are three wires, left, right and top. So you've got a choice. You can go to the right or to the left. The left is where you were from.

Both groups stated that they used similar techniques for collaboration. The visually impaired user in both groups was the expert in the area and they lead the discussion on how the circuits worked, initially identifying the components for the sighted user and explaining how the arrangement affected the circuits, introducing terms such as serial and parallel. The job of the sighted user very often was first to give an initial overview of the circuit, by saying for example for P1:

VI: Ok, so what's the overall shape?
S: It's a rectangle with a line down the middle.
VI: Ok. I'm on the battery.
S: Ok, you're on the top at the middle.

A similar example for P2 would be the sighted user stating once the circuit was loaded "*Right so just now you're going down the left, and there's still a battery in that place just like the last one*". Here she is providing information about the shape of the circuit (building from previous examples) and the visually impaired participants cursor position in the circuit.

By following the visually impaired users' cursors, they constantly provided information about the visually impaired users position in the circuit, and which directions could be traversed next. There were many examples of this such as the sighted user stating for P1 "*and that's you at the middle of the top then*" or for P2 "*At the moment you're going up and down the left hand wire*". These were by far the most common contribution by the sighted user.

At no time did the sighted user in either group interact with the visually impaired user by moving the Phantom. Only verbal guidance was given. This indicates that the visually impaired users were quite capable of navigating the circuits themselves. This might also be due to the fact that it was the visually impaired users who were the experts in the area and were very much leading the discussion of the circuit. Both visually impaired users were able (after some initial input from the sighted user) to maintain an idea of their position within the circuits. One good example of this from the visually impaired user from P1 saying "*And its saying that I can either go up or to the right. So up is back to the battery so if I go to the right. Now that means I'm coming onto another plain piece of cable. There' s nothing on that. Junction… so that means I guess that I'm back vertically to just below where I started*". Both visually impaired participants stated after the study that they were building up a metal representation of the shape of the circuit with the visually impaired participant in P2 drawing the circuit with a finger on his hand while describing it.

Video observation showed that in all circuits and for both groups the visually impaired user traversed all potential paths in the circuit. Both visually impaired users commented on the clearness of the tactile cues and displayed through the VTPlayer tactile array. Only one identification error was made in the entire experiment, where a battery was mistaken for a capacitor, and this was quickly corrected by the sighted user.

One aspect of the interface that initially caused confusion was due to the different representations provided to the sighted and the blind user. When the Phantom cursor moved onto a wire, the tactile pattern for the component on the wire was presented to the visually impaired user at all points on the wire. The sighted participant was unaware of this which initially caused confusion when discussing the component. *Post hoc* discussion of this feature suggests, however, that all users felt it to be a valid and valuable feature once this misunderstanding had been resolved. For example, for the users in P1 when the Phantom cursor is on a wire above a bulb:

> VI: *Oh and I'm on a bulb as well. Is that correct? I think.*
> S: **hesitates**
> VI: *a cross?*
> S: *Ah. The cross bulb is further down, so go down…. Keep on going down.*
> VI: *So what we're getting is as soon as I go onto the cable where the cross (is). That's the actual cross there. So I think what is happening in a tactile sense is as soon as I get onto the cable that's got the bulb on it but even before I get to the bulb itself, its telling me that's there's a bulb on that cable.*

2.5 Discussion

It is important to remember that above we describe the results of a pilot study. The key things to be drawn from this study are firstly what the interactions between the users occurred, and secondly how do these results inform the design of a full study.

For both groups, the sighted user was important for providing an initial overview of the circuit. They were able to continually update the user on their position within the circuit and possible directions to move. Although the visually impaired participants in this study were able to maintain an awareness of their position within the circuit, this will not necessarily be true for users with less experience of circuit diagrams. This might also be true of larger circuit diagrams. A wider range of complexities of circuits should be present in the final experiment. Both visually impaired users commented that the circuits were navigable with little collaboration after initial input from the sighted user. They stated that they would be far more likely to collaborate more if more components and more complex circuit structures existed such that it was harder to retain a mental image of the circuit.

This initial evaluation has suggested that there is promise for this interface as a collaborative teaching tool. However, there are a number of issues to resolve before a large scale evaluation is possible. Firstly, there was no way for the sighted user to interact with the environment since the visually impaired user had control of the only interaction device. This did not prove so much of a problem here due to the fact that the visually impaired users in this study were experts in the area, and led the exploration and the discussion. For a situation where the blind and sighted participants are on an equal level of expertise, this may become problematic. The sighted users here were able to get a quick overview of the circuit through a visual representation, but were relying on the expertise of the visually impaired user to explain different aspects of the circuit. It will be important for the final evaluation to provide a method (other than physically grabbing the visually impaired user's device) for the blind and sighted users to interact in the environment. The sighted user could follow the movements of the blind user by watching their cursor, but the blind user did not have a similar technique for know what area of the circuit the visually impaired user was focussing on. This could be solved by incorporating a second interaction device into the environment and allowing the two devices in to interact and locate each other.

There were also problems identified when the haptic and visual representations display slightly differing representations. This occurred when the Phantom cursor was on a wire with a component, while not being on the component itself. The tactile information presented to the visually impaired user was indicating that they were on the component where as to the sighted user it looks as if the visually impaired user was feeling a wire. Once both users became aware of this issue however, this form of presentation was felt to be beneficial to the visually impaired user as it made it easier to find components on the circuit diagram while not changing the logic of the circuit.

2.6 Conclusions

In this section we have described a pilot study to evaluate a haptic environment for teaching circuit diagrams in a non-visual manner. We have examined the behaviour of two pairs of users – one sighted and one blind - collaborating to gain a fuller understand of five circuits of varying complexity. The results suggest there is good potential for using this environment as a tool for teaching electric circuits. It is important however to consider how two users work together in the environment. For the final evaluation, we will look to provide an input device for each user to allow interactions between the users. This study has provided a good basis to inform future studies examining this environment as a collaborative teaching tool. The results show that it is possible for both blind and sighted users to work together in this environment to understand simple electrical circuits. Future studies will expand on this with a wider range of participants, while examining more complex circuits.

3. Planning a Theatre Play in a Shared Multimodal Scene

The overall purpose of this application is to allow visually impaired users to create and access graphical images. The application has been developed in close collaboration with a user reference group of five blind/low vision school children. The study presented is a pilot study on the use of the drawing application in a collaborative task that involved exploring of graphical images of the Shakespearean Globe Theatre.

3.1 Application evaluated

The application prototype makes it possible to make black & white relief drawings. The Reachin 4.1 software is used to control the haptic device, which can be either a PHANToM OMNI or a PHANToM Premium. The sound effect playback is based on the FMod API, and the Microsoft SAPI 5.1 text-to-speech API is used to make the application talk. A mouse can be used simultaneously to the PHANToM to enable collaborative use, although the application can be used by a single user also.

The application consists of a room with a virtual paper sheet, which both users can draw a relief on. The PHANToM user can also feel the drawn relief (or an imported pre-drawn relief). When the PHANToM pen is in touch with the virtual paper the user draws on it while pressing the PHANToM switch. The mouse user draws while pressing the left mouse button. The haptic image is produced as positive or negative relief depending on which alternative is selected. The relief height (depth) is 4 mm. The drawing can be seen on the screen as a grayscale image – a positive relief is seen as black, and a negative relief is seen as white (figure 1). The paper color is grey.

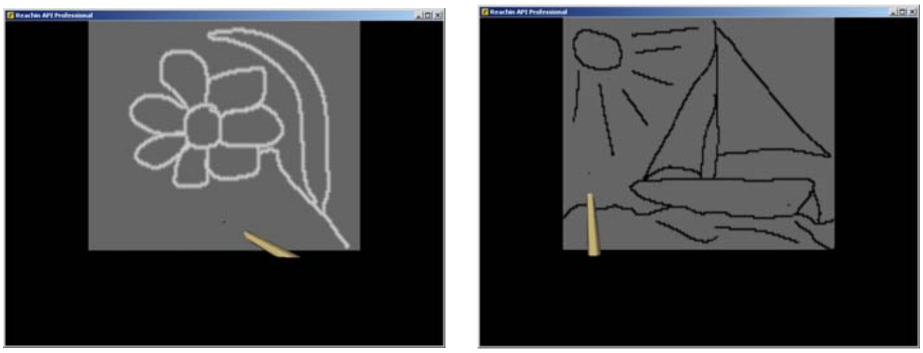


Figure 1. Screenshots of the drawing program in negative relief to the left and in positive relief to the right.

While drawing, the PHANToM user can feel the other lines that have previously been drawn and thus connect parts of lines and feel intersections. Furthermore, each line (or single object) is attached with a spoken number and text tag. This number and text tag is spoken by the application each time a user selects an object by touching it with the PHANToM pen or hovers over it with the mouse cursor.

There are a number of tools that can be of help to the users while drawing. The objects can be manipulated in the following ways: moving, resizing, copying, pasting, deleting, changing text tags, inverting to outline shapes: rectangles/squares, ellipses/circles, straight lines.

All manipulation tools are fitted with a feedback sound, and auditory icon that is supposed to help the user understand the progress of the manipulation. The auditory icon is designed to resemble a real world manipulation of similar nature. E.g. the copy function sound effect is a camera click.

Furthermore, the mouse user can guide the PHANToM user by a pulling force that drags the PHANToM pen tip to the mouse cursor position. This also enables the mouse user to point and reference to objects. The PHANToM user can also place force beacons at specific points in the environment, to enable fast and accurate return to these points.

A png import function has also been implemented and thus completed drawings including vector graphics and text tags can be saved and reloaded with the program.

3.2 Evaluation overview

3.2.1 The evaluation context

The test was conducted in a high school second grade class in an arts education program. About a third of the pupils each have chosen to specialize themselves in the subjects theatre performance, musical performance and visual arts. At the specific test occasion, 16 pupils were present in the class. A blind pupil is integrated in the class, having a specialized workstation with computer, Braille display, speech synthesis and a Braille writing keyboard. The pupil will normally get visual material transferred to tactile images on swell paper (figure 2). This is done by an assistant who also transfers images to another blind pupil at the same school.

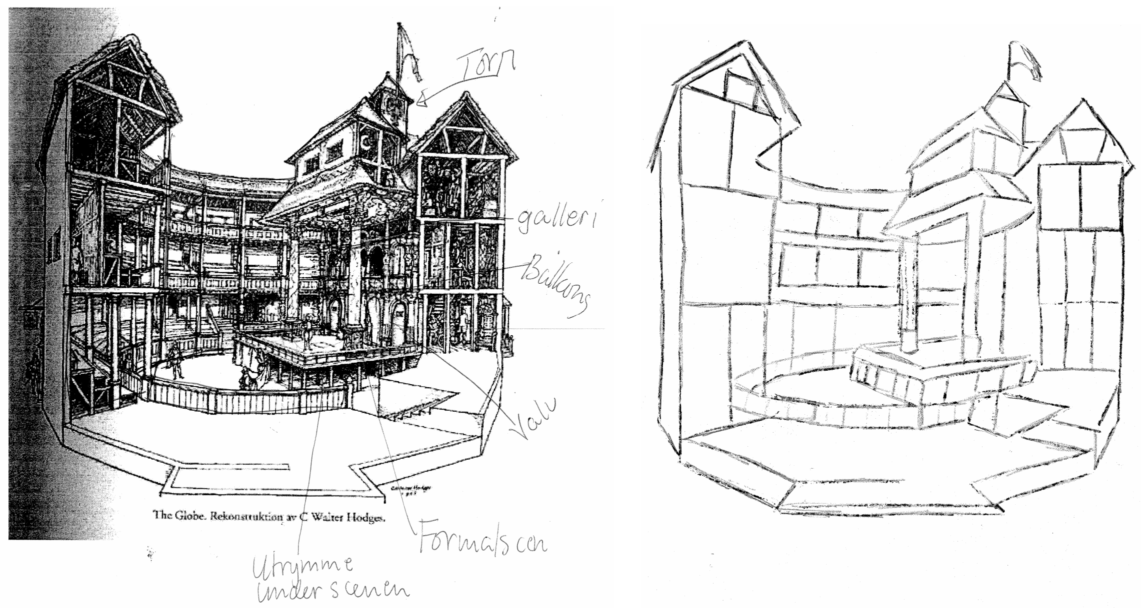


Figure 2. The original paper material for the task. The left figure shows the image used by sighted pupils, and the right figure is a copy of the tactile image prepared for the blind pupil.

3.2.2 The task and procedure

The learning task was to, on the basis of an image of a traditional Shakespearean theatre (i.e. The Globe) place the actors on different parts of the stage and balcony etc. in every scene of a Shakespeare play, either The Storm or Macbeth, which they had read in advance. The image was marked with the different parts of the theatre – e.g. formal stage and balcony.

The teacher started the task by describing it verbally to the pupils, while also showing an overhead image of the stage. The teacher pointed at the different stage and theatre parts and also explained where the pupils possibly could place actors, both by pointing at the overhead picture and by describing and naming them. All sighted pupils were handed a copy of the theatre image with the different parts marked.

The grouping of the pupils had been done beforehand, and they were supposed to work two-by-two with the task. The pairs were allowed to spread out anywhere at school during the group session, and all pupils except four left the classroom to sit in the large corridors where tables and chairs were places here and there for doing school work. Some pupils also headed for the library and a special classroom for free studies. The blind pupil did not want the classmates (except the partner) to see the test arrangement, therefore a small room adjacent to the classroom was used for them.

Usually, the blind pupil would get the visual material transferred to tactile images on swell paper. Instead, the material was transferred to image files on the computer, which were interpreted by the audio-haptic drawing program. The images were then marked by the researchers with the drawing tools in the drawing program, with names and information about the different stage and theatre parts.

There were 4 different files with stage information to choose from (figure 3). One drawing was a simplified variant of the tactile picture that the assistant had previously prepared for the pupil. There was also a simplified cross-section from above and then a view in front of the stage. Both the latter drawings were also included into one file with somewhat smaller details.

The pair of pupils could choose freely between the files, using the one that suited them best. Pressing a shortcut on the keyboard would start a standard Windows file load dialog that was supported by JAWS to enable text-to-speech outside the drawing application.

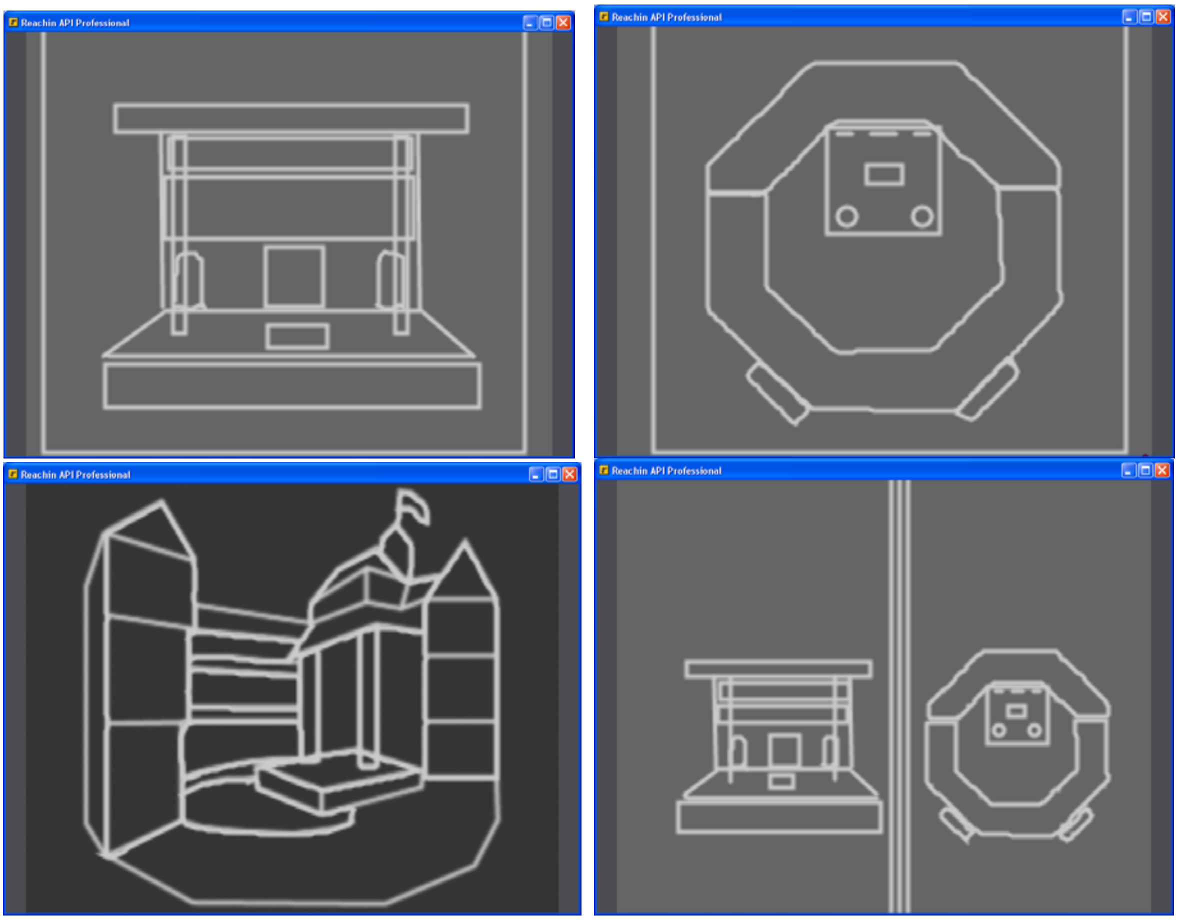


Figure 3. Screen dumps of the four different files/views accessible of the Globe Theater.

3.2.3 Analysis of the collaboration process of the group with one visually impaired

The video-recorded group work task and the interview were both transcribed and analysed with an analysis software called Transana. Two transcriptions were made, one of the task and one of the interview. The transcription for the recorded group work task was divided into the 21 scenes that constituted the task. Apart from analysing the group work session as a whole, each of these scenes were accordingly considered as important building blocks.

In the analysis we considered these aspects:

- General usability
- Exploration and navigation
- Guidance
- Learnability
- Common ground
- Awareness
- Initiative/involvement

3.3 Results from the observation analysis

In this section the results from the analysis of the video recorded test session of the group with a visually impaired is reported with regard to the aspects listed above. When appropriate, recommendations will be made about changes in the interface and the task.

3.3.1 General usability

From the very beginning it is evident that the visually impaired pupil finds the equipment easy to use. She does not seem to be experiencing any problem when it comes to feeling the different lines. From the first scene and ahead she uses the phantom naturally and she understands how to use it. The same thing could be said about the sighted pupil using the space mouse.

One thing, though, that seemed to confuse the visually impaired pupil was the drawing showing two different perspectives. Three lines were separating the two drawings and the voice said “new drawing” on the middle line and the respective names of the drawings on the other two lines. She followed these lines back and forth and she did not seem to understand their purpose. Once she even said “very strange”. Maybe it would be a better idea to have just one drawing in each file.

One other thing, concerning the different files and drawings, was that the voice said “<name of file>dot txt” each time a file was loaded. The subjects did not comment on this, but maybe the .txt-part could be omitted. Anyway, the drawings were obviously easily followed and the subjects did not often “slip over” lines.

The visually impaired pupil seemed to like the voice, even though she got a little frustrated towards the end of the group work session. She commented that it was a good idea that the voice said the drawing’s name when the border was touched. Towards the end of the evaluation she made a great effort in trying to avoid the voice, since it interfered with the discussion between the subjects as soon as she moved the avatar to a new line. She was genuinely angry in one of the last scenes when saying “Yeah, yeah, yeah”. Maybe it would be a good idea to let the phantom user decide (for example by pushing the button) if he/she wants to hear the voice or not. Another idea might be to omit the voice when the line was touched by the sighted user, so as not to confuse the visually impaired one. There was no sign of confusion caused by the voice in this context, though.

The navigational guiding function was frequently used for the intended purpose. The guiding operation was successful most of the time, but on a few occasions the sighted pupil mistakenly dropped the visually impaired one. Sometimes the visually impaired pupil got a little irritated when she was guided without prior preparation – maybe there could be some kind of signal alerting about this. However, apart from this the function was easy to use.

The subjects gave the impression of believing the task to be too long and complex. In the beginning of the group work session they seemed to enjoy the task but after they had solved half the assignment they started yawn and saying things like “this takes too long” and “how many scenes are left?”.

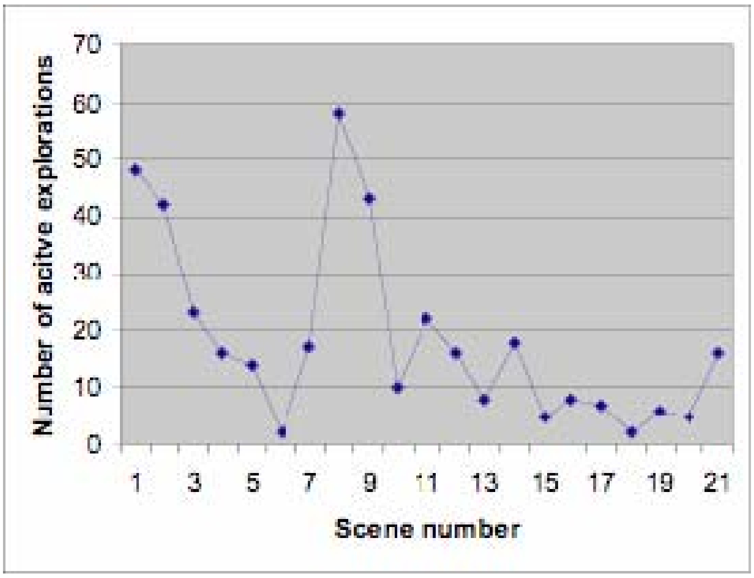
3.3.2 Exploration and navigation

In total, the voice was activated 386 times due to active exploration. Most of these voice activations were made in the beginning when the visually impaired pupil needed to get an overview of the respective drawings. The voice activations that were caused by the sighted pupil’s exploration are not included in this sum. Table 1 shows how the number of active explorations evolve with time (i.e. scene number). As can be seen in the diagram the number of active explorations needed decreased as the work progressed, with the exception of a peak in the middle scenes and in the end. The peak in the middle scenes could be explained by the sighted pupil reading for himself for a long while – the visually impaired pupil had nothing else to do than exploring the scene.

Except from what is discussed above the overall trend is pretty clear – the need for active exploration decreased as the work progressed. From this, one should be able to conclude that the visually impaired pupil could get a mental model of the drawings pretty fast, which is positive for the application.

There is also a small peak in the 11th scene worth an explanation. In this scene someone in the task scenario is entering a room after coming into the castle. The subjects decided to let the room be on the balcony and that the person should come from one of the vaults. To get a better understanding of the settings the visually impaired pupil started to navigate to the left vault, thereafter she followed the two other vaults to the back of the scene and then up to the balcony. After this she was pleased and they proceeded. This was the first time she navigated as the person in the story and she had no problem finding her way to the balcony. Accordingly, this shows her to have a good mental model of the drawing and that the lines were easily followed.

Table 1. The number of active explorations per scene in the group work task



Another example of the same phenomenon was found in scene 20, when they once again decided where a person should come. First the sighted pupil decided that the person should come inside from one of the vaults and then the visually impaired one navigated directly to the main vault and told him that she wanted to use it. It seemed like she actually wanted the voice to tell the sighted pupil which vault to choose. This is an interesting example in which the visually impaired pupil drives the discussion further by active exploration.

3.3.3 Guidance

Haptic guidance was provided by the sighted pupil for a total of 32 times during the whole group work session. In the beginning the sighted pupil used this function to show the visually impaired one the different parts of the drawings. For example, in the first scene he starts by guiding his co-worker around the "whole perspective"-drawing (he shows the floor, the columns and the different floor levels). Funny enough, when the sighted pupil did not identify the main vault he guided the visually impaired pupil to a place that actually happened to be just that and asked "what is that?". After a little while they switched to a new drawing and the same procedure was repeated in the new perspective. In the next scene they switched to the last drawing and the sighted pupil again started off by guiding the visually impaired one around. She seemed to get a pretty good understanding of the overall layout during these initial guiding operations and this shows the importance of having such a function. Obviously it was not hard to understand what this function could be used for by the pupils.

Later on, the sighted pupil only used the guiding function when he wanted to focus the visually impaired one's attention on a specific part of the drawing or when he was not sure if she understood what he meant. For example, in scene 5 (the first time they decided to use the balcony), the sighted pupil guided the visually impaired fellow around the balcony during their discussion about it. On some occasions the visually impaired pupil said she did not know where certain things were placed and then the sighted one used the guiding function to inform her. Once again the haptic guiding function was shown to be a valuable contribution to the interface.

Another interesting example of the use of this guiding function was in scene 7, when the visually impaired pupil wanted to place a room in the gallery. The sighted one thought that the gallery was too small and he used the guiding function to point out the differences in height between the gallery and the balcony. This time, this guiding function was used by the sighted pupil to convince his co-worker that the gallery was not such a good idea.
The guidance provided by the computerized voice was also used to get an overview, especially in the first few scenes. The visually impaired pupil said numerous times things like "it is good that she tells you what it is". She often talked about the voice as was it belonging to a real person and she even joked about the pronunciation from time to time. Thus, the voice seems well chosen and it obviously served an important role in the interface. During the last few scenes, however, she got very frustrated with the voice and tried to avoid it as much as she could.

The different perspectives available also served as a kind of navigational guidance. When something was hidden behind something in one drawing they changed the drawing to make the scene appear from another perspective.

3.3.4 Learnability

As stated earlier the subjects experienced no problem in using the respective equipment. They learned quickly how to use the space mouse and the phantom and they used the functions and the different perspectives exactly as intended. In the first few scenes the visually impaired pupil needed to move around the drawings all the time and she also needed guidance. Later however, she managed to find her own way through the interface when she needed to get a better understanding of the setting just being discussed. She also learned how to navigate without necessarily triggering the computerized voice.

3.3.5 Common ground

Common ground was established very early in the group work process. In the first few scenes the visually impaired pupil needed guidance and active exploration to get an overview but later on she did not need it any more. Already in scene 3 they could discuss the spatial layout of the castle and where it was appropriate for people to come up on the main scene. It was very interesting to hear how they naturally talked about where the rooms were and where people came and went.

On the few occasions where the subjects disagreed on the spatial layout, the haptic guiding function got useful. For example, as mentioned above the visually impaired pupil first thought the gallery was quite big, but she changed her mind after being guided to the gallery and balcony respectively. Thus, the haptic guiding function was used as a means of establishing a common ground, and it worked.

Another interesting example showing the two subjects to share a common ground is the following dialogue concerning scene 18:

Visually impaired:	We have not used the gallery.
Sighted:	Yeah, but I do not know what the gallery is... It is a very small space above the balcony.
Visually impaired:	Yes...
Sighted:	We have not used the tower either
Visually impaired:	No, but I think it will come to use later.

Obviously, both subjects are very much aware of having not used the gallery or the tower. Also, they obviously agree on the position and size of the gallery. This example shows pretty well that they have established a common ground by use of the application.

Another evidence for a good common ground is that the visually impaired pupil, especially in the last few scenes, navigated to the area that was being discussed. It seems like this was a way of making sure that they were speaking about the same thing.

3.3.6 Awareness

The visually impaired pupil also seemed to get a good amount of awareness in the interface. She got this awareness through the haptic guiding function and the computerized voice heard during her as well as from his active exploration. In the first few scenes she was a little bit uncertain but she learned quickly how to use these different sources of awareness. The computerized voice always told her where she was and when a new drawing had been uploaded and it also reminded her of which drawing they used when she touched the borders.

Also, the visually impaired pupil quickly got a good overview of what was happening in the story they were told to direct. Already in scene 3 she saw a problem when some people should enter the scene, where the witches were used shortly before (they decided, though, that the witches had left the scene). Another informative example of this can be found later in scene 11, when the sighted pupil wanted to place a room on the balcony. She accepted and commented “that is where we have all the rooms”. On several occasions the visually impaired pupil sees problems with the main scene becoming too crowded. Another interesting example is in scene 14, where the sighted pupil wants to use “the hell”. The visually impaired pupil, though, had such a good understanding of the setting that she realized that people in the hell could not be seen by the audience. After a perspective switch the sighted pupil agreed with her.

3.3.7 Initiative and involvement

The visually impaired pupil was included in the work process during most of the time. The only exceptions were when the sighted pupil read the text silently for himself. Of course they did not need all the text to solve the tasks, but this silent reading of his was no positive contribution to the work process and it decreased her sense of awareness. The first few times the sighted pupil was reading for himself the visually impaired one explored the drawing, but later on she evidently became bored and started to continuously ask things like “what happens next?” and “what is happening now?”. Maybe it would be a good idea to have the text spoken by a voice similar to the navigational guiding voice. In that way both subjects will get the same amount of information. Except for this problem the visually impaired pupil was always involved.

When it comes to initiative they were pretty much on the same level. In the beginning, when the visually impaired pupil was still in the learning stage the sighted pupil came up with most of the ideas, but later on the visually impaired one was more eager to decide. None of them seemed to have the decision-making role, they discussed every task jointly until agreement.

It also happened from time to time that none of them were taking the initiative to solve a certain problem – somehow they agreed in silence. This happened most often during the last few scenes when they had got a good idea about proper places for everything. They knew each other’s opinions and the overall layout well enough to be able to see things as obvious.

The visually impaired pupil was always the one taking the initiative to move on, much because she was not included when the sighted pupil read silently for himself. When it came to initiatives for exploring the interface the sighted pupil was, of course, taking the initiative in the beginning when he had to guide the visually impaired pupil. Later on, though, the visually impaired pupil was taking more initiatives on her own, when it came to exploring the interface and showing what she was talking about. From this, it may be concluded that the visually impaired pupil was feeling more self-confident as her mental model of the drawings were refined.

3.4 Results from the interview

In this section the results from the interview with the visually impaired pupil will be presented. The audio recording has been transcribed word for word and a content analysis has been made.

3.4.1 The group work task and working method

The visually impaired pupil is not very used to group work projects in school. It happens from time to time that she solves smaller assignments by cooperating with someone else, but on those occasions it is most often up to herself. She generally enjoys working and interacting with her classmates.

Anyhow, she found this group work task nice and she felt she had a pretty good idea of what was being done and why. She found the task a little bit hard in the beginning, but she said that, “after I had got an overview of the theatre it was pretty easy to place things”. She thought it took her about 10 minutes to gather the overview needed to proceed with focus on particular parts of the drawings.

In general, the blind student said that when she is working with pictures, she uses a special kind of paper that, processed by heat, displays the black lines in relief. She feels the lines that makes up the picture by moving her hand over the paper and finds this way of working with pictures somewhat rough and with the details difficult to feel. It is much easier and funnier working with the phantom – now she can feel things and especially details in a completely new and better way. Working with pictures was also much easier in this program, because she could be guided to different places. Especially, she emphasizes that this was her first opportunity of collaboration about pictures, “you can actually do that now!”. She also commented that “now you can do things like the others.” – before this, she could only get an oral description.

3.4.2 The haptics and sound

As noted above and much thanks to the phantom, the visually impaired pupil found this way of working much easier. The phantom was used to “look at” the pictures in a totally different and better way. The haptics made her more convinced that both of them were talking about the same thing.

Working with the phantom was a little bit hard in the beginning, but she believed that she learned its operation pretty fast. She had a lot of practice with the phantom prior to the evaluation. She also found the haptical guiding function very useful. Compared to oral guiding, this was found a much better means. For example, she said that it is more cumbersome to hit a certain spot if the co-worker says things like “further to the left and then to the right” when several minutes may be required to get to the right place. No problems were found with this function but questioned about roles, she whished she could herself play the role of guiding somehow.

When asked about the voice she said spontaneously “I think it was good to have her there”, immediately reminding of her using “her”. She thought the voice facilitated collaboration, for example she could point out things by using this voice. She also believed the voice made it much easier to navigate, especially in the beginning when everything in the scene was new to her.

3.4.3 Common ground and social presence

The visually impaired pupil thought that both she and her co-worker shared the same picture, much due to the phantom. When they disagreed about something she was guided and found this very useful. The feeling of having all information in common made it much easier to discuss and collaborate, according to her.

Especially she pointed out the importance of being in the same environment, feeling the presence of the other person. She meant that the guiding function helped her a lot in getting that feeling. Knowing that you are in the same environment makes you more confident “that you always talk about the same thing”.

3.4.4 Awareness

When it comes to awareness she found it hard now and then to know what her partner was doing unless he did not explicitly tell her. But she said this was no problem, elaborating with “even if you can see you do not sit down and look where the other is watching”. Most of the time, though, she felt aware of the co-workers action and what was happening in the interface.

3.4.5 Initiative and involvement

The visually impaired pupil felt involved in the whole working process and seemed pleased with the way they took turn in solving the tasks. She did not see any major differences when it came to taking initiative, they were pretty much on the same level. When they wanted to tell each other something they both showed what they were meaning in the drawing. She also thought she had a good understanding of the story because the text was read to her the day before. When asked about her strength in the work situation, she once again said that they could to the same things, because they had and could access the same information.

3.4.6 General usability

The visually impaired pupil found the different perspectives very useful. She had a hard time finding out which one was the best but was aware of the “front” perspective being used in most of the scenes. She believed each perspective served its own purpose, the one showing the front was best at presenting the balcony, gallery, etc, and the one from above was good for closer study of the scene. An interesting remark, though, is that she never realized they had worked with a drawing divided into two perspectives.

She liked the voice, it was helpful and sounded okay despite being artificial. Among the strengths with the program was that she could explore the scene, easily feeling details, and hear the voice simultaneously. The potential of this kind of application when it comes to working with and collaborating about pictures was clearly seen by her. She also thought it could be a great help when making oral presentations in front of the class. Pointing out in a picture what is talked about is hardly possible at present.

As an idea about improvements of the application she thought it might be useful to have differently textured material at different places. For example, some things could be rough and some smooth. This could make it even easier to navigate.

3.5 Results from observation of the sighted pupil’s collaboration

The sighted pupils were observed during their collaborative work. Since the pupils were spread out in the school building, it was not possible to easily observe the whole work process for all pupils; instead the groups were observed one by one part of the time. Since the task was built up of a repetition of similar subtasks (to place actors on the stage for each scene in a play), it was inferred that a group would go about to work in approximately the same way for each scene.

The groups would work in an overall similar manner. They discussed one scene after another, often returning to the play text to refresh their memory about the details of each scene. Usually, the pupils discussed each scene and then wrote a note on paper about the placement of actors in the scene. Sometimes they would point at the picture of the theatre with a pen or a finger, and also make gestures in the air to help describe the movement of actors. A handful of occasions occurred when a pupil also made a simple drawing explaining where on the theatre he or she thought the acting should take place. One group (that was still in the classroom) used the overhead projector picture to point to. The same group also stood up under a larger portion of the task, acting out parts of the scenes.

The different pupils had noticeably different motivation levels for the task. While many of the pupils actually in the beginning had problems understanding the given task, most of the pupils started working quite seriously. According to the teacher, the pupils were doing the task in a more detailed manner than planned. A handful of the students were more poorly motivated by the task and spent some time among them to argue about the relevance of the task in respect to the subject. However, they still solved the task, but quite uninspired. It seemed – and it is not too surprising - that the pupils that were best motivated for the task were the ones that had chosen theatre performance as their specialty.

3.6 Discussion

It is interesting to se the progress in how the visually impaired student uses the interface over time in this study. The visually impaired student explores the different parts of the drawing constantly in the beginning of the task at the same time as she is discussing with the sighted pupil about how to solve the task. This frequent exploration fades out during the session and in the latter half of the session the exploration takes place only when a specific spatial problem is discussed. It is apparent that the visually impaired student first explores a lot in order to get a mental understanding of the special layout of the scene and the parts of which it consists. When she has obtained this mental understanding the pair has developed a common ground about this and only investigate the drawing occasionally.

The reason why the task was so demanding, about 80 minutes, was that the teacher designed the task. Usually researchers limit the total test session time to a maximum of 1 hour. This fact that we could learn about the development in use over time can be a good methodological design in the final evaluation. It has been shown in many of our studies that the learning phase and exploration phase is quite long and it can be argued that it is not possible to se the true potential of a system until quite some time has passed.

In this study it is clear that the guiding function is very useful. The guiding function is used frequently and efficiently. It is so seamless that the sighted student can drag the visually impaired student to many different points in the drawing in a series and they can do this while discussing about the content simultaneously. The only thing that is a bit problematic is that the use of this function is o easy that the sighted user forgets to warn about his intention to move the visually impaired student, which disturbs her slightly. In the interview the visually impaired student said that it would have been good if she could drag the sighted user, but she in the next sentence says that it did not matter so much that it was not possible. In the future however, it would probably be advisable to include the possibility for the visually impaired student to drag the sighted one.

It this study the work situation was not disturbed by bugs and other problems with the system, it was very stable. That was probably the reason why we could see that the group work went very smoothly and that the system was not very noticeable but worked as an effective tool. The group work was also noticeable equal with no dominance from any of the group members. Decisions were most often made in consensus, both sometimes argued their case, and they were both included equally much in the final decision making. This is one lesson to take away from this evaluation that in order to observe functional group work, the system design has to at least be usability tested so that unnecessary bugs do not disturb the group process. This might sound self-evident but is easy to underestimate.

4. Group Work about Natural Phenomena in Space

In the study conducted in the University of Tampere in May 2006 we wanted to investigate how does the Space application with one Phantom device suit for visually impaired and sighted child's collaborative exploration. The application is designed for a single user and in this phase we didn't implement any new characteristics for collaboration support. Two children were placed in front of the phantom device and we observed their behaviour when using the Space Application (figure 1). Testing took place in May and the initial analysis has been done in June 2006. The second analysis has been made in January 2007 and in this latter analysis we have focused on those parts of testing procedure where children are resolving the tasks given to them by the test assistant. In this chapter the results of the second analysis will be introduced.

Figure 1: Children using the Phantom stylus together

Our tests have taken place in a usability laboratory and thus our results are not fully comparable with the results of the field studies. This analysis has been done however using the parts of our testing procedure where children were completing specific tasks. The situation was thus somewhat like the circumstances when doing group work at school. Of course in the laboratory the other classmates are missing, which makes the use situation more undisturbed than in ordinary classroom. In our previous analysis (D9) we found out that the child holding the Phantom stylus dominated a bit in a group work. In this new analysis we will further examine this phenomenon and we try also to investigate if both children were equally committed to the tasks on hand.

4.1 Application evaluated

The Space application is designed to support children's explorative learning. In application the children can study natural phenomena, which are related to the Earth, the Sun and the Solar System. The simulation consists of six applications or so called micro worlds, of which four were on in our tests. These parts were: the Earth, the Solar System, the Earth's Orbit and the Earth's Internal Layers. As input devices have been used a Phantom device and a Magellan Space mouse. The first is used for haptic feedback of the micro worlds and the latter is used for navigating back to the central station, which is the menu of the application.

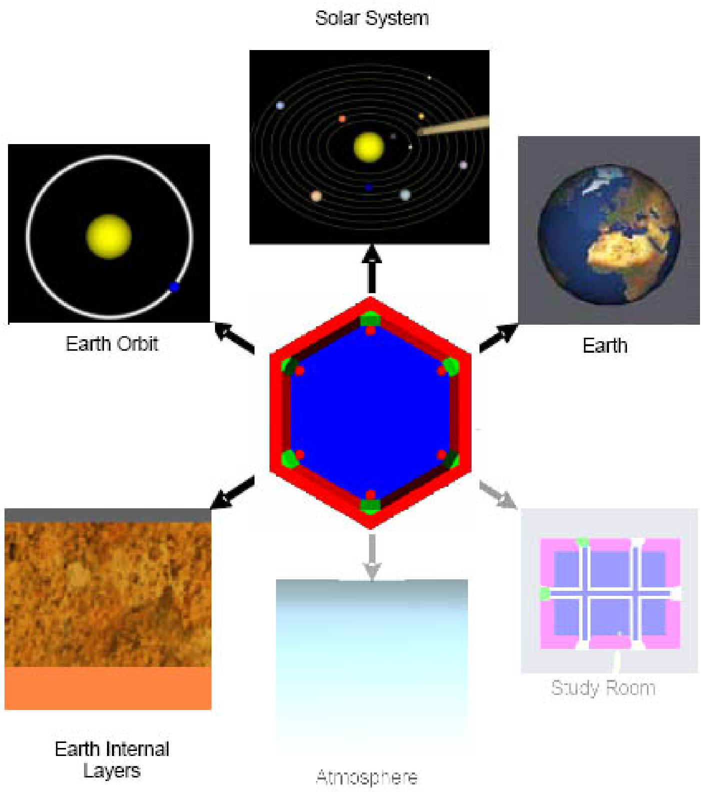


Figure 2: The Space application as it was implemented in our tests in May 2006. The figure has been modified from [Saarinen et al., 2005].

The application has been described more detailed in Deliverable D12: "First versions of the software architecture and applications for the children".

4.2 Evaluation methodology

The study was conducted in UTA in collaboration with KTH. The pilot test was planned and conducted by three researchers from UTA and one researcher from KTH. After the pilot test four pairs of children (one visually impaired and one sighted) were invited to our laboratory to test the Space application. The participants are introduced in table 1.

Table 1. Background information about the participants in the evaluation.

	Pair 1		Pair 2		Pair 3		Pair 4	
Sight	Blind	Normal	Blind	Normal	Vis.Imp.	Normal	Blind	Normal
Age	11	11	12	12	9	9	11	10
Gender	M	M	M	M	F	F	M	M
Relationship	Twins		Cousins		Schoolmates		Siblings	
Experience of tactile device	No	No	Yes	Yes	Yes	No	No	No
Experience of Phantom device	No	No	No	No	Yes	No	No	No

The testing procedure of testing with visually impaired children has been developed in our previous research projects [Raisamo et al., 2006]. The procedure of this study has been fully described in Deliverable D9: "Reports on results from empirical studies of collaboration in cross-modal interfaces". In this testing procedure the children first used and explored the application independently. After that they were asked to complete three different tasks concerning the application. They were told to use the application anyways for completing the tasks, even if they knew the answers beforehand (or after the independent exploring). Those tasks were the following:

1. What different reasons affect the fact that Earth is the only planet with life in our solar system?
2. One part of the application contains information about the oceans and continents of the Earth. Which continents are not mentioned there?
3. It is said that if you dig a tunnel deep enough, you will come out from the other side of the Earth. Why isn't this possible in real life?

This analysis is based on children's non-verbal expressions and their actions when completing the tasks. The analysis is made from the video recordings of the test situations. The observed non-verbal expressions and actions are listed in Table 2.

Table 2. Observed non-verbal expressions and actions made by the children.

Non-verbal interaction	Actions
leaning in partners direction	using the Phantom stick alone
pointing	using the Phantom stick together
nodding	pushing the button
shaking one's head	grasping the stylus
leaning forwards	elbowing another's hand out of the stick
laughing	additional (outside of the tasks) actions
smiling	
jumping etc.	
leaning backwards	
yawning	
swivelling one's chair	

4.3 Evaluation results

4.3.1 Activity

The children were active in all pairs. They completed the given tasks together. Although the visually impaired child was the "main user" of the Phantom stylus, they also changed roles during the tasks when needed. For example in Task 2 one visually impaired asked the sighted child to complete the task with the stylus. He was however actively involved and was listening and discussing about the task.

The joint use of the stylus occurred basically by sighted child as an initiator. This was quite obvious as the visually impaired child was mainly using the stylus. In one test the visually impaired child held the stylus all the time by both of his hands. This led to some troubles in using the stylus together with the other child.

4.3.2 Dominance

In those cases where children were not so much used to work together (they were schoolmates or cousins, not twins or siblings) the visually impaired child seemed to dominate a little. This came out when visually impaired child was active and enthusiastic in doing the task and the sighted child (also enthusiastically) grabbed the stylus but released it immediately when the visually impaired ignored this activity.

In the case of the twins the visually impaired child pushed the other's hand away from the stylus some times, but there were no signs of actual dominance; this pair worked seamlessly together as they would have had a joint work plan. None of them needed to dominate; both of the children were concentrated to the common task.

4.3.3 Commitment

The children concentrated quite well to the tasks. Most of them had however already knowledge about the application area and maybe this reduced a bit their motivation in completing the tasks. In some cases we noticed additional actions (outside of the tasks) by the sighted child who was not handling the Phantom stylus. This happened when the child didn't have so much to do at that time with the application. In the same way when the visually impaired child leaves the Phantom stylus, he or she is not able to do so much with the application.

4.3.4 Completing the tasks

All the pairs managed to do the tasks. In one case it happened that the visually impaired child answered right (in task 2: Which continents are not mentioned there?) although the pair didn't visit that continent at all. He just remembered that he didn't hear the name of the continent. Test assistant approved the answer but asked the sighted child to check the issue from the application.

4.3.5 Assistance

One of the pairs came off well and completed the tasks independently. This pair also worked very well together. Three other pairs needed some help, either verbal guidance or concrete, in using the stylus.

In one case the program failed and it had to be booted up. This affected to the concentration of the children and they needed help to continue with the tasks. Otherwise they coped very well. One pair didn't collaborate so well and they needed reminder from the assistant both in working together and in completing the tasks.

4.4 Discussion

The child using the Phantom stylus seems to easily dominate in collaboration. Usually this child is the visually impaired one, who is seated in front of the Phantom device. In this case the role of the sighted child is more like an assistant than a participant. This combination seems to continue when children are completing the tasks together. Although the sighted child evidently wants to grasp the stylus, he/she hesitates to do that or the visually impaired child even pushes the other's hand away from the stylus. One solution to avoid this situation is to offer both children their own input devices.

There could be much more visual information for the sighted child as the haptic feedback is mainly directed to the visually impaired one. This could increase the commitment of the sighted child to the learning situation. The sighted child should also get clear visual feedback about the haptic feedback that the visually impaired gets. Then he/she could more easily guide the other one in navigating and exploring the application. On the other hand there could be another haptic device for the sighted child to get the feelings of the haptic feedback. This device could be for example a vibration feedback game pad. This could be a good solution for collaboration as well because it is not practical and ergonomic to use the Phantom together so that the child has a hand on top of another's hand. The haptic feedback will not appear true in that case.

If the role of the sighted child is mainly guiding and observing, it will be quite difficult to motivate him/her to explore the contents of the application and thus to collaborate. The content should be designed so that it is interesting for both sighted and visually impaired child. It should be remembered however to keep the amount of the sounds in pleasant level and on the other hand to offer visual feedback so that it will not disturb concentration to the application as a whole. The sensing of visual information is fast and the processing of that information is selective and less distracting than auditory or haptic feedback. Thus all the visual information may not need to be represented for the visually impaired as the sighted child can bring that extra information to the learning situation.

5. Demonstrators

Demonstrations of the applications evaluated in this Deliverable 10 is available on the MICOLE project web-site (http:// micole.cs.uta.fi).

6. Published Papers

Several papers have been published on the research done in WP3 that is relevant for this report.

6.1 UGLAS

Crossan, A., & Brewster, S. (2006). *Two-Handed Navigation in a Haptic Virtual Environment.* Paper presented at the In Extended Proceedings of CHI, Montreal, Canada.

Crossan, A., Brewster, S. (submitted). Multimodal Trajectory Playback for Teaching Shape Information and Trajectories to Visually Impaired Users. *ACM Transactions on Accessible Computing.*

6.2 METZ

Pietrzak, T., Noble, N., Pecci, I., & Martin, B. (2006). Evaluation d'un logiciel d'exploration de circuits électriques pour déficients visuels. Dans *RJH-IHM 2006*, Anglet, France.

Pietrzak, T., Pecci, I., Martin, B. (2006). Static and dynamic tactile directional cues experiments with VTPlayer mouse. Dans *Eurohaptics 06*, Paris, France.

Pietrzak, T., Martin, B., & Pecci, I. (2005). Information display by dragged haptic bumps. Dans Enactive 2005: *Proceedings of the 2nd International Conference on Enactive Interfaces*, Genoa, Italy.

6.3 KTH

Sallnäs, E-L., Moll, J., and Severinson Eklundh, K. (accepted, 2007). Group Work about Geometrical Concepts Among Blind and Sighted Pupils Using Haptic Interfaces. *Proc. of The Second Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (World Haptics 2007).*

Winberg, F. (2006). Supporting cross-modal collaboration: Adding a social dimension to accessibility. In McGookin, D. & Brewster, S., *Proceedings of HAID 2006, First International Workshop on Haptic and Audio Interaction Design*. pp. 102-110, Springer Berlin / Heidelberg, Glasgow, UK, August 2006.

Sallnäs, E-L., Moll, J., and Severinson Eklundh, K. (2006). Haptic Interface for Collaborative Learning Among Sighted and Visually Impaired Pupils in Primary School. *Proc. of the Third International Conference on Enactive Interfaces (ENACTIVE 2006).*

Sallnäs, E-L., Bjerstedt-Blom, K., Winberg, F., and Severinson Eklundh, K. (2006). Navigation and Control in Haptic Applications Shared by Blind and Sighted Users. *Proc. of the First International Workshop on Haptic and Audio Interaction Design*, pp 68-80. Springer Berlin / Heidelberg, Glasgow, UK, August 2006.

6.4 ULUND

Rassmus-Gröhn, K., Magnusson, C., Eftring, H. (accepted, 2007). Iterative design of an audio-haptic drawing application. *CHI 2007*, San Jose, USA.

Magnusson, C., Rassmus-Gröhn, K., Eftring, H. (2006). A virtual haptic-audio line drawing program. *3rd International Conference on Enactive Interfaces*, pp 20-21. November, Montpellier, France.

Rassmus-Gröhn, K., Magnusson, C., Eftring, H. (2006). User evaluations of a virtual haptic-audio line drawing prototype. *Workshop on Haptic and Audio Interaction Design University of Glasgow*, 31st August - 1st September.

Rassmus-Gröhn, K., Enabling Audio-Haptics, Licentiate Thesis, Certec 2:2006, Department of Design Sciences, Lund University, September 2006, Lund, Sweden

7. Recommendations for Methodology and Design

7.1 Based on the evaluation of the Electrical circuit application

1. Allow all participants a method of interacting with the environment. Set up your experiment to give everyone access to an input device.

2. When one user is more knowledgeable in the subject material then they will tend to dominate the task. Be aware of this when designing the task and make a conscious decision on what roles the different participants should have.

3. Qualitative observation of user interactions can provide as much information as more quantitative data.

4. Provide a task that requires a goal for both users such that one user cannot complete the task by themselves.

7.2 Based on the evaluation of the Drawing application

1. A longer test session gives information about the learning process of especially the visually impaired participant and also about the development of how the groups develop strategies for using the system in the group work.

2. Let the teacher design the task in order for it to be contextually valid and also for it to be taken more seriously by the students.

3. Give equal possibilities to guide and grasp one another in the interface, guiding is potentially very useful but it should be provided to all participants equally.

4. If possible, give all material needed for completing the task to both the visually impaired and sighted participant like for example written instructions. Otherwise, one of the guidelines formulated in MICOLE is not met, namely that the aim should be to avoid parallel work processes.

5. Grasp functions that move one participant to another location might be more respectful if a subtle warning signal is given just before the physical movement. Another possibility is that the action also can be overridden if movement is not wanted at that particular time.

6. If possible, observe and interview not only participants in the group with the visually impaired pupil but also the other pupils in the other groups working in the class in order to be able to compare the groups.

7.3 Based on the evaluation of the Space application

1. Provide input devices of some kind to all children that participate in the group work so that all children can interact and explore the workspace.

2. According to our tests it is important to carefully plan the tasks for the children and the equipment needed in test situation. Some pairs in our tests for example wanted to write down the answers of the tasks. They asked to have paper and pencil, which did not include our testing plan. Those are anyways very common tools for children in school environment. On the other hand the application could offer the opportunity for making notes. This has been taken into consideration when further designing the application and the MICOLE architecture.

3. The Space application is designed to be used as a part of children's explorative learning. Testing the application in a laboratory separated from the learning situation in classroom does not give the best view of its benefits for children's collaborative learning. That is why it would be better to aim for testing in schools even if that needs more effort than testing in a laboratory.

4. Another methodological issue to take into consideration is that it would be better to have a teacher involved in planning the tests according to the curriculum. The learning environment and thus the test situation will then me more authentic.

8. Conclusions

All three evaluations show that there is a delicate balance in how access to feedback to the different senses affect the interaction between the participants and how they manage to collaborate. In all three evaluations the participants managed to complete the task together. They managed to get a shared understanding of the workspace and both participants were in all cases very much involved in solving the tasks. So, the recommendation that was formulated early on in this project that parallel work processes should be avoided has been met rather well.

However, even though the participants largely collaborate well together the fact that they still get different information from different senses and more or less of the actual instructions and information needed in order to complete the task affects their collaboration. In the case of the Electrical circuit, the sighted user can see the spatial layout but does not get the written instructions about the components that only the visually impaired user gets through the VTplayer mouse. This affects the collaboration in such a way that the sighted participant is expert in knowing directions whereas the visually impaired person is the expert in the use of the components. In this case then, we have a situation were both participants have to rely on each other’s expertise in order to complete the task. This is an interesting result, which means that both participants should get as much of the needed information as possible in a way that is as equal as possible. However, if this is not achievable, a clever division of labour can be an effective approach.

This discussion about equal access to functionality and information is also relevant in the case of guiding of another participant. All groups rely a lot on verbal guiding. But, for example in the case of planning a Shakespeare play using the Drawing application, the students reported that the fact that the sighted could grasp and relocate the visually impaired student haptically to the area that was discussed, saved them a lot of verbal direction making. Also, in the Geometrical applications presented in D9 the fact that one can “haptically hold hands” and talk about the task simultaneously helps the participants in their problem solving and sense of awareness. This was something that the results from the evaluation of the Describe and draw application in D9 indicated would have been better than that the sighted person first draws the right shape and the visually impaired student later follows it haptically. Simultaneous haptic guiding and verbal discussion in real time is a very valuable tool for successful collaboration. It is probably also the case that the best scenario is if both the visually impaired pupil and the sighted pupil can take the initiative to haptically guide, grasp and relocate another person.

Apart from the useful guiding functionality, all possible means for interaction by both participants seems to be important for the perceived involvement in the task. This means that even if the sighted pupil gets almost all information that is needed from the visual information and indirectly from the visually impaired user’s interaction with the environment, like when sound information is given in the Space application, it seems as if being able to interact actively in the environment is as important for the sighted as for the visually impaired user. Here again we have to take care that we not cater so well for the visually impaired user that the needs of the sighted users are put aside. No one benefits from unequal prerequisites in a group work situation. We started of by observing the blind child being cut off from the group work process in the initial field study in schools and now we have in some cases almost cut the sighted pupil off from essential information and functionality in our aim to efficiently support the visually impaired pupil. This is really interesting, and an important issues to take into careful consideration for the future studies.

It cannot be said often enough that the most important prerequisite in order for these applications to be useful for collaboration is that they are usability tested in order to ensure that they are stable and free from bugs. In the evaluation of the Space application a system crash damaged the work process considerably and broke the pupils concentration. This happened in the pilot studies of the Geometry application also, and it was very clear that the group work process is in itself so demanding that an unstable system might be fatal to the group’s performance. If the task is rather complex a system crash can make it impossible to solve the task. This is probably, as always, one of the most important things to avoid for the final evaluation of the system.

In conclusion, the results from the evaluations made in the MICOLE project which has been reported in D8, D9 and D10 have accumulated a large amount of knowledge about collaboration between visually impaired and sighted pupils in group work in multimodal and cross-modal environments. Lets not forget that the reason for doing this project was to support inclusion of visually impaired pupils in a learning activity that is becoming increasingly important in school, namely group work. This is one of a few unique projects that investigate this particular setting and user group and the results will serve as a good base for future research in this area.

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