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MICOLE
Multimodal collaboration environment for inclusion of visually impaired children

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Version 1.1 (13.10.2007): Added an experimental study in which the hypothesis that auditory feedback increase efficiency in a haptic collaborative application was tested. Both quantitative and qualitative results were obtained in this experimental study.

Summary

This report describes a number of empirical studies of collaboration in multimodal interfaces performed in the MICOLE project, Work Package 3 (Task 3.3). The studies have been conducted in three different countries (Sweden, Scotland, Finland). A meta analysis of the field study, that was done year one is also presented in chapter 8. This meta analysis has been written by researchers at UPMC in France in dialogue with researchers at KTH in Sweden.

The aim of Task 3.3 was to conduct empirical studies of collaboration in multimodal environments between sighted and visually impaired persons. These empirical studies aim at investigating aspects of concern that were discovered during the activities year one in particular in the field study of group work in schools.

In this report, five evaluations of collaborative applications are presented. Furthermore, the design of one more collaborative system is described as well as a description of future evaluations of it. The evaluations that are presented in this report have resulted in a number of guidelines that are presented for each evaluation respectively but also collected together in chapter 7.

The guidelines presented in this report, will inform the design of the final technical system developed in Work Package 4. The guidelines can hopefully also be useful for researchers outside this project. It is important to remember is that these evaluations have been conducted in different contexts and the guidelines are therefore more or less specialized. However, a number of common themes are starting to emerge, that we argue are a good starting point for formulating guidelines that can be generalized more. To achieve usable guidelines that can be generalized is one of our main goals with the rest of the work in this project.

1 Introduction

The MICOLE project is aimed at developing a system that supports collaboration, data exploration and communication for visually impaired children and their peers as well as their teachers.

Support for collaboration is an essential part of the system developed in the MICOLE project, because collaboration facilitates social learning between the disabled and sighted children. That is why one important aim is to allow blind people to create, manipulate and share information to work with other blind and sighted people and to take a full role in society and work at an equal level with sighted people.

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. The focus is mostly on auditory and haptic modalities in order to give information that would otherwise be provided through visual cues. However, the visual modality will still be used to allow pupils that have some sight left and sighted children to use the system together. This makes it possible for both our target group and sighted children to use the same environment together.

1.1 Background

Computer-supported collaborative learning (CSCL) is an extensive research area within computer science. In this area, collaborative applications with pedagogical aims are investigated. Groupware are systems that support distributed or co-located cooperation, coordination and communication (Sauter et al., 1995). It is not only the technological solutions that are in focus but also how the applications affect users socially and psychologically. Issues that are investigated are for example if the application increases the social interaction and the collaboration between pupils and what kind of learning aspects that the application supports. Fundamental research questions in the area are:

- How should an application that supports learning be designed?
- How can one ensure that the users learn what the application aims at teaching?
- Is it easier to learn something with a computer application than through more traditional teaching?
- Can education become more efficient if computers are used in school?

There are principally two perspectives on learning in primary school; developmental psychology and the socio cultural perspective (Gustavsson and Holmberg, 2004). The developmental psychological perspective has been the dominant perspective which argues that pupils go through a number of specific developmental stages. Characteristic for this perspective is also that the pupil's level of knowledge and skills is compared with the level of adults. Therefore, the pupils are always been regarded as less knowledgeable. In the socio cultural perspective the focus is instead on communication and social interaction between the pupils. In this perspective, it is argued that the pupils interpret the environment they live in and actively create their own conception of the world as well as their knowledge with the help of their interaction with peers and teachers. The contact between people and the context is therefore important factors to consider for the construction of knowledge. Development in the socio cultural perspective is according to Säljö (2000) "a socialisation into a world of actions, conceptions and social interplay that are all cultural". The socio cultural perspective is getting more and more important in education in school today.

There are three types of learning that are interesting to consider; problem based, social and constructive learning. In problem based learning the view is that the pupils themselves can find and collect the knowledge they need in order to solve problems (Dahlgren, 1998). Teachers that use problem based learning in school let the pupils find relevant information for the topic and solve the problem with their obtained knowledge instead of getting the solution from a lecturing teacher. The argument is that if pupils independently apply their knowledge that they themselves have obtained they will get a deeper kind of learning than if they just listen to lectures. Group work in school where each group gets a problem that they are supposed to solve together is one example were this kind of learning is practised.

According to the theories about social learning a lot of the knowledge a person has is aquired by studying how older people as well as people of the same age behave (Bandura, 1977). In this theory it is argued that a person learns how to act in different situations by looking at behaviours, attitudes and reactions of others – one learns through imitation of others. The most common form of social learning is to imitate and learn from one's parents. In school, group work can contribute to social learning. It is also argued that the context as a whole has to be taken into consideration as an important factor that affects learning.

Constructive learning means that a pupil learns through active hands on work with things, building models, planting or laboratory work for example (Carlson, 1998). The fundamental idea is that the pupils themselves should actively search knowledge by doing things preferably in a realistic setting. According to this theory a person always learns best if she is active both mentally and physically. Laboratory work in school is a rather frequent example of constructive learning. Many computer programs that make it possible to build things also fall into this category of learning tools.

The conversation between student and tutor and between pupils is an essential part of the learning process. This learning process should be discursive, adaptive, interactive and reflecting. The visually impaired pupils that are the main user group in MICOLE do not have access to visual input like mimics and gestures when communicating with peers and teachers. However, haptic and auditory feedback together with talking verbally in shared collaborative interfaces could compensate for some of the information that these pupils otherwise does not have access to. In order to cooperate, groups and individuals have to coordinate their activity through communication. Underlying processes to coordination are decision making, communication and perception of common objects like physical objects or shared databases (Malone and Crowston, 1990).

People's level of awareness of others activities has been identified as important for cooperation in groups (Gaver et al., 1991). The concept of awareness is generally used in terms of individuals' perception of others' activities and the status of others' work-processes. When people that cooperate do not have the opportunity to get this kind of information, if they for example work in a distributed way, studies have shown that they do not reach the same quality in joint projects (Kraut et al., 1993). In the case of visually impaired and sighted pupils' collaboration in school, this general awareness has to be transmitted through other senses than vision, which limits the information that the visually impaired pupil gets compared to the others. This might make it harder for the visually impaired student to obtain awareness. However, a shared multimodal interface that represents group activities and objects in complementary ways, that both sighted and visually impaired pupils can use might give "shared" awareness.

1.2 User requirements from the field study year one

A number of requirements were formulated from the results of a field study that was performed in five countries in parallel year one in MICOLE. The most important were the following.

1. The focus should be on creating shared workspaces in order to avoid parallel work processes. The field study showed that in many cases the pupils' visual impairment resulted in using different material than the other pupils that was not so interesting or accessible (Braille text) for the sighted pupils during group work. The material that the blind pupil used was sometimes also much more finalized which made the blind pupil being in another phase in the group work process. These parallel processes destroyed the intents of the pedagogical method of group work that aimed at social and constructive learning.

2. It is important to support collaboration and communication both between students and between students and teachers. In France group work is not so common and the blind pupils go together in small classes in specialized schools. The pupils in this case, work together with the teacher partly in a dialogue but most often the teacher has traditional lectures. However, also in this case we argue that the biggest problem is the parallel work processes that the pupils have and that the teacher has respectively. Because the classes are so small the pupils could hypothetically work together in a shared workspace with the teacher overlooking the pupils' processes on a visual display while teaching at the same time. This would probably improve the mutual understanding of the learning process.

3. It is important to support both browsing and exploring of information/data on the one hand and creation and modification of information/data on the other hand. Many systems for blind pupils today mainly support consumption of information like reading text, feeling maps and graphs and so on. However, in order to do well on tests of knowledge in school the pupil also has to be able to produce information. This is also the very essence of constructive learning theory. In order to be a valuable group work member it is vital that each pupil can produce material both during the work process and when presenting the results.

4. Something that we cannot address in this project but that is important to have in mind is that it is important to take the whole social context in the school into consideration, both during classes and during breaks. The social activities during breaks are very important for the social training of the children in general. A conclusion from the field study was that the blind pupils were not included in the

other children's activities during breaks. The blind pupil was in fact very often totally alone. One reason for this is that the breaks are outdoors and the games are very mobile which is problematic for the blind child. The activities during classes are much easier for the blind pupil to follow as they are planned by the adults in order to also include the blind pupil.

1.3 Objectives of this work package

The objective of this Work Package 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 second year, these objectives were addressed in Task 3.3 (Empirical studies of collaboration in cross-modal interfaces). The aim of Task 3.3 was to conduct empirical studies of collaboration in multimodal environments between sighted and visually impaired persons. These empirical studies aim at investigating aspects of concern that were discovered during the activities year one in particular in the field study of group work in schools. One essential problem was that it is important to create shared workspaces in order to avoid parallel work processes where the blind pupil due to special equipment is not included as much as they want to be. Furthermore, it was found that it is as important to make it possible for the visually impaired pupils to produce information as it is to support consumption of information in order for the child to be able to contribute in group work. It was found that visually impaired pupils do not do group work in all countries in Europe but that the interaction between the teacher and the visually impaired pupil should be addressed as a collaborative situation.

A number of prototypes developed in MICOLE have been evaluated in collaborative situations. In these studies issues such as general usability, specific support for blind pupils, support for the social interaction, support for learning and inclusion have been investigated. Based on the results from these studies general conclusions have been drawn and guidelines for design of multimodal interfaces for collaboration between sighted and blind persons have been formulated.

1.4 Task 3.3 Empirical studies of collaboration in cross-modal interfaces

Royal Institute of Technology, KTH has been co-ordinating the work that was done in order to get the empirical studies started at the different locations. Researchers at KTH have arranged work meetings with the different partners that have been involved in task 3.3 in order to plan and design empirical studies of collaboration between sighted and blind persons. A pilot study was for example performed jointly by researchers at Tampere University and Royal Institute of Technology, in March 20-21 this year, in Finland. Furthermore, a meeting was held between KTH and UPMC this year in order to have a dialogue about the meta-analysis that has been made of the field study results performed year one by University of Pierre and Marie Curie.

2 Group Work about Geometrical Concepts Including Blind and Sighted Pupils

Royal Institute of Technology, KTH

2.1 Introduction

In the study presented in this report two haptic and visual prototypes for learning about geometrical concepts in group work in primary school have been evaluated. The prototypes shall support collaborative learning between sighted and visually impaired pupils in primary school. The first prototype was a three-dimensional environment that supported learning of spatial geometry. The scene is a room with a box containing geometrical objects, which you can pick up and move around by means of a haptic feedback device. In the other two-dimensional version, the scene is a board on which you can feel angles and geometrical shapes of drawn figures. In both versions the sighted pupils can see the scene on a horizontal flat screen. The two program versions were evaluated in four schools with small groups of two sighted and one visually impaired pupil. The results were encouraging, especially regarding the two dimensional version, yet we got ideas for improvements. The results showed that the support for the visually impaired user was good and that co-operation and learning are satisfactorily supported. Also promising was that the power of the touch-based haptic interface for supporting visually impaired people was made clear.

2.2 Background

There are several computer programs that are used in order to support collaborative learning. A few examples are pedagogical computer games, (Alexandersson et al, 2001), Internet, word processors and different virtual environments.

Hägg and Petersson (2003) have studied the effects of using computers as tools for learning in school for blind pupils. They interviewed five teachers and four pupils regarding the effects of using computers on communication, inclusion, the work situation and also how the technology functioned generally. One conclusion was that the computer solved many of the earlier problems but that using computers in the education also had negative consequences. Generally it was concluded that the computer can be useful in increasing integration and inclusion in the school context.

At large, the attitudes towards computers in school were positive among both pupils and teachers. Regarding inclusion and social interaction the pupils thought that the computer was a good help. Above all, the computer provided an increased interaction with sighted peers and teachers because of the fact that they could see, follow and understand what the blind pupil wrote. Inclusion also increased due to this as it became easier to work in groups. Another advantage with the computer was that the blind pupils got the same tasks as the sighted pupils, at the same time during class, because it is easier to write the tasks in a computer than making a swell paper copy.

Earlier the teacher or assistant had to go through the task separately with the visually impaired pupil after she had given the task to the class that had at that time already started to solve the task. Using the computer the teacher can prepare the task and give it to both sighted and blind pupils at the same time. All parties also report that the visually impaired pupil manage to accomplish more when using a computer, especially regarding reading and writing. The teachers thought that the computer functioned as a link between the blind and sighted pupils and thus increased the level of involvement of the blind pupil in social interaction. A positive thing with the computer generally was the possibilities to use the computer for reading and generating text in Braille so that the pupil did not have to carry around so many Braille books. Because the blind pupils also could use the computer to transform Braille text to black text she could more easily show others what she had produced in text. The most negative thing with the computer was that the technology often failed to work. This was regarded as a very serious problem both by the teachers and the pupils. If the computer did not work the pupils often had to be without it for days and then it was really obvious how much the pupil and the teacher relied on it. Another disadvantage was that the blind pupil was dependent on the knowledge and attitudes of the teacher towards technology.

2.3 Aim of the study and research questions

The aim of this investigation was to evaluate the collaboration in a shared haptic environment regarding usability, collaboration, learning and inclusion in a group work process including blind and sighted pupils.

- How should a haptic feedback interface be designed in order to support group work in comprehensive school?
- How can a haptic interface be created that supports collaboration between visually impaired and sighted pupils?
- Does our evaluation show that this has been achieved?
- Which guidelines can be found from the results of this work?

Apart from the requirements from the field study, a number of application specific requirements were formulated. The following requirements were more detailed.

1. Three pupils should be able to do group work with the system including one visually impaired pupil.
2. The system should be both tactile and visual using a flat screen and Phantom displays.
3. The system should support group work in the topic of geometrical concepts.
4. The interaction environment should be in a closed space with fixed reference points.
5. Users should be able to grab each other in the environment and guide each other physically.
6. Collisions between objects should be felt through haptic feedback.
7. Gravitational forces should be used on objects in the environment.
8. Users should be able to physically pick up objects and move them and drop them in the environment.
9. Users should be able to hand off objects to each other.

2.4 Hardware

The following hardwares are used when working with the prototype:

- One personal computer (with ReachIn API 4.0 and Visual Studio 2003 installed)
- One flat LCD screen (lying on a table with horizontal surface)
- Two phantoms (one Desktop and one Omni) connected serially to the computer
- Keyboard and mouse

2.5 Software

2.5.1 The Angle Prototype

In this prototype the scene is a kind of board on which one can feel angles and geometrical shapes of drawn figures (see Figure 1). The idea is that this prototype should support learning of two-dimensional geometry. The buttons at the bottom of the picture are used by the teacher to create new "lines" and to save and load pre-constructed scenes. When the pupils are using this prototype these buttons are disabled (they have no function) and the positions of the lines are locked. All lines are instances of the Box node in Reachin API. Every line can be felt as a narrow, centimetre high "wall" along the line that prevents passing and enables the user to feel it without slipping over. The width and length of the lines are possible to change as described below. The teacher can create new lines according to preference. After pushing the "New line" button a default line appears with a predefined rotation, width, length and location. A toolbar also appears with slide bars where the teacher can change these values. The new line can also be "grasped" and moved to the right location. The drawn shapes of figure 1 have been created by a repeated use of this procedure.

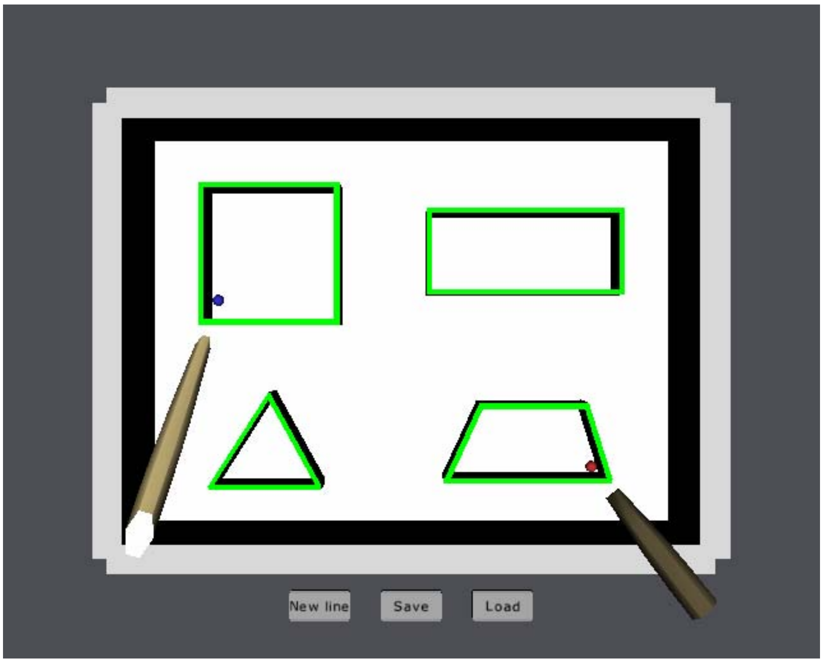

Figure 1. Two persons investigating geometrical shapes in the Angle prototype.

2.5.2 The Cube-moving Prototype

The cube-moving prototype is a three-dimensional environment that supports collaborative learning of spatial geometry (geometrical shapes such as cube and cone, the concept of volume). The scene is a ceiling-less room with a box on the floor containing geometrical objects, such as sphere, cube, cone and cylinder. Figure 2 shows a screen shot of this prototype with the box in the far left corner. The floor, ceiling and walls are all instances of the IndexedFaceSet node in Reachin API (the objects which are instances of this node can be penetrated from one side but not the other, if a user ends up outside the room he/she can always get back inside again). The roof, walls and box all have different textures applied to them that one can discriminate between.

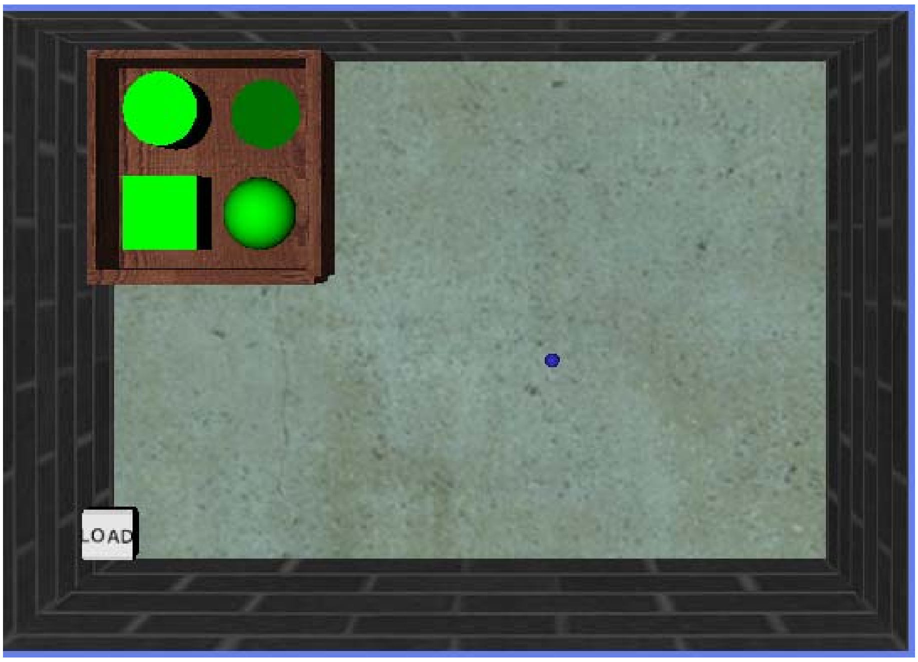

Figure 2. A three-dimensional cube-moving prototype that supports collaborative learning of geometry.

Apart from feeling and recognizing the different geometrical shapes a pupil can also pick up and move around the objects by means of the phantom. Since gravity is applied to the objects the pupils feel the weight and inertia as they carry around things. The objects in the box, which in fact are ten overloaded objects of each type, may also be placed on each other. In this way pupils can use the objects in the box to compose larger objects.

Besides feeling and manipulating objects users can feel and grasp each other's graphical representations to provide navigational guidance e.g. to a visually impaired fellow. The users can also "feel each other" by means of a small repelling force, applied whenever the users' graphical representations touch each other.

In yet another version of this prototype, not treated in detail here, the teacher can create new objects of the types seen in the box. In that version, the teacher is enabled to create a new scene and save it. In this manner the teacher may create a task in advance. The teacher can then, before the pupils start to use the program, press the LOAD button seen in Figure 2 to load the pre-created task.

2.6 Evaluation

A task driven evaluation was performed in the field and the context was group work in primary school. Two haptic prototypes for practicing geometric concepts in 2.5D and 3D respectively have been evaluated in this study.

2.7 Method

2.7.1 Participants

The participants in the evaluation came from four different primary schools in the Stockholm area. In each school the teacher of the class that had one visually impaired pupil was contacted. The teacher handled the contacts with the parents of the pupils that were involved in the study. That meant that the teacher informed the parents about the study and also obtained the consent on a consent form from them.

In total, twelve pupils participated in the evaluation in four groups of pupils with one visually impaired and two sighted pupils in each. The pupils were all between 11-12 years old. Three of the four blind pupils were girls and four of the eight sighted pupils were girls.

One of the visually impaired pupils were totally blind, one pupil had very little sight left that did not have any effect on the evaluation and two pupils had some sight left that might have had a slight effect on the evaluation.

In three of the four test sessions the teacher or the personal assistant were present but did not interact much with the pupils during the group work.

2.7.2 Procedure

The evaluation was divided into five parts with two training sessions, two group task sessions and one interview session with all three pupils together after they had done the tasks.

First of all, the researcher gave introductory information about the aim of the evaluation. Then the pupils were instructed how to use the haptic devices. The researcher made sure that all pupils, including the visually impaired pupil, really got an understanding of how haptic feedback feels and what can be felt in the interface.

2.7.3 Tasks

The pupils first tried a training application with four geometrical shapes to get an understanding of how to feel surfaces and objects (Figure 1). Their training task was to classify the geometrical shapes, square, triangle, cuboid and trapezium. After the training a new task was uploaded in which the pupils should distinguish between a right, obtuse and acute angle (Figure 3).

The first group work task was formulated as follows.

At the bottom of the box there is now a new, large shape. You shall now decide for each angle in the shape if it is right, obtuse or acute.

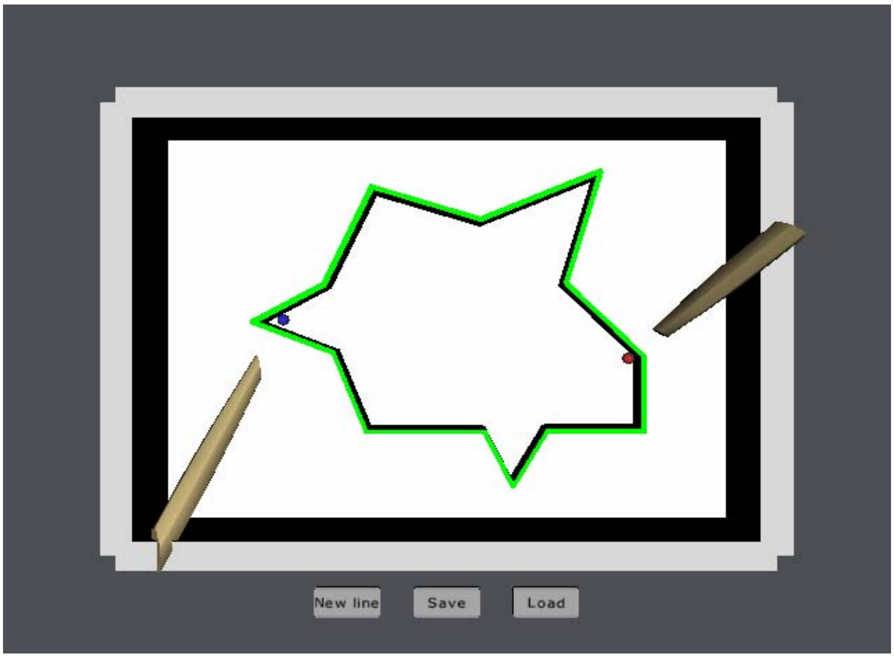

Figure 3. Pupils are exploring the angles in a star shaped figure in order to distinguish between right, obtuse and acute angles.

When the pupils had completed the first task and made a consensus decision about the angles a new three-dimensional training application was uploaded (Figure 4).

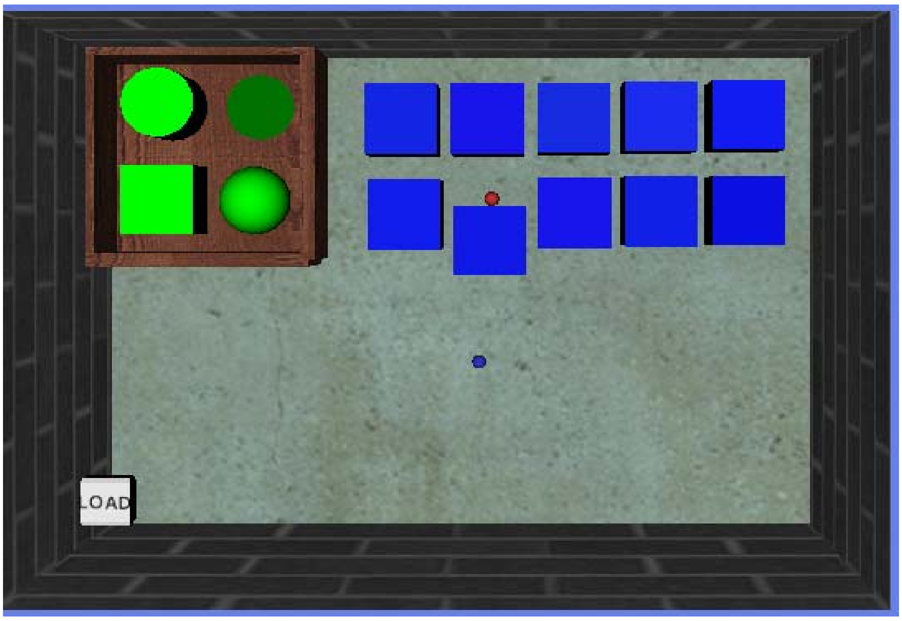

Figure 4. Pupils are practising using a three-dimensional haptic and visual environment with ten cubes on the bottom of a closed space and a ”wooden” box in the left corner.

The pupils had practised feeling the shape of the cube and the three-dimensional environment and also how to grab a cube and lift it and hand it off to someone else. When the pupils practised for some minutes the environment was uploaded again (Figure 5) and they got the group work task that was the following.

- *There is like before, ten cubes to the right of the box. All cubes have 2 cm long sides. You shall now place the cubes on the floor so that they cover a cuboid with the area of 32 cm^2. Tip: How large an area does a cube cover?*

The pupils were instructed to move as many cubes as was needed in order to cover the area. They were also instructed to not use the objects in the box but the researcher pointed out that the box could be used as a reference point. They could in this environment lift cubes together and guide each other just as if it was physical cubes.

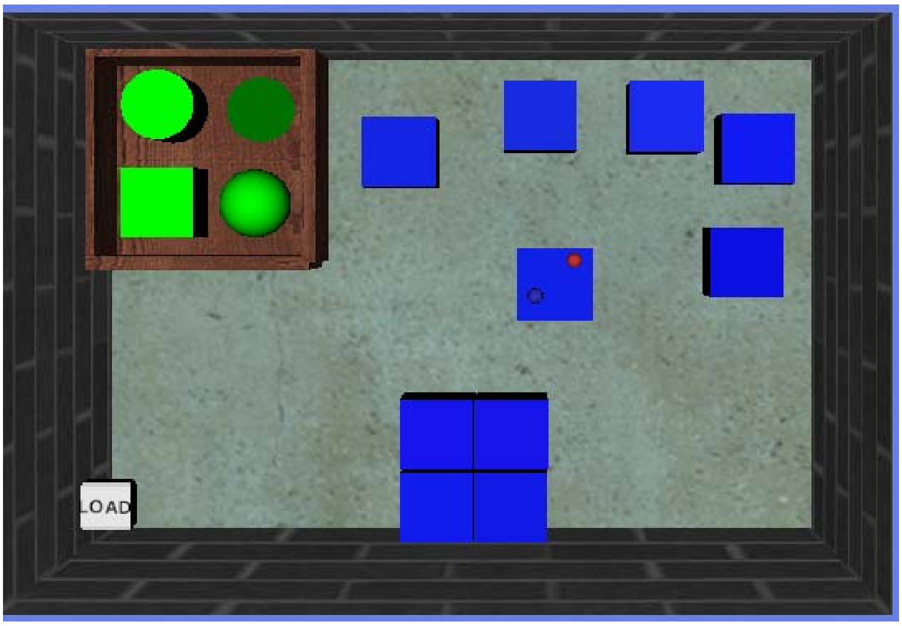

Figure 5. Pupils are half trough the second task in the three-dimensional haptic and visual environment and two pupils are holding on to a cube and are moving it to the target area.

2.7.4 Interviews

When the pupils had completed their tasks they were interviewed in groups, all three together. An open form of interview was used and the researcher used the following five items.

1. Was it possible to feel were different things were placed and what shape they had?
2. How was it to perform the tasks together?
3. Was it boring or fun to collaborate using this tool?
4. Do you think that this is a good way to learn math or not?
5. Do you think that you solved the tasks mostly by yourself or did you do it together?

The interview items aimed at exploring the pupils' thoughts about usability issues regarding haptic feedback, the possibilities to collaborate in this type of environments and their attitudes towards this kind of tool for learning purposes. Follow up questions were asked in an informal way in order to achieve a relaxed dialogue with the pupils. The pupils were also encouraged to complain about the applications as we made it clear that they were only prototypes. This proved to be very fruitful, and the children became more honest in their feedback.

2.7.5 Analysis

The video recorded sessions of group work were analysed and notations were made for each session. The dimensions that were used for the categorization of the notations were: general usability, how the system supported learning, collaboration during group work, inclusion in the work process and finally how the system supported the blind pupil specifically.
The recordings of the interviews were transcribed word by word but neither emotional expressions such as laughter nor sighs or pauses were notated. The results from the interviews are presented together with the observation data.

2.8 Results

2.8.1 Support for the visually impaired pupils

In the Angle prototype the visually impaired pupils were able to use the whole work area in a good way and the borders of the environment and the corners were used as reference points. The figure was easy for all blind pupils to find and the shape was easy to follow which is necessary in order to be able to distinguish parts of a shape.

Also in the Cube-moving prototype all the blind pupils could easily find their way in the environment, use the “wooden” box and the corners as reference points. All blind pupils also could differentiate between the different textures on the surfaces of the objects and walls and floor and used that information for navigation. All blind pupils also managed to lift cubes and move them and place them somewhere else in the environment and could even hand off cubes to the sighted pupils. The guiding function was also used by most blind pupils.

However, the Cube-moving environment was much harder to use for the blind pupils than the Angle prototype due to a number of issues. The fact that the environment was dynamic, cubes were moved around at the same time as cubes moved if the blind pupil explored the shape of it made it hard for the blind pupil to keep track of changes. This resulted in the blind pupil making mistakes when trying to place one cube next to another in order to perform the task of covering an area with eight cubes. The blind pupil did not know where the others had put a cube and there was no information about where the target area was. Some of the groups solved this problem by holding on to the same cube as the blind pupil and guiding her to the intended place.

The conclusion made is that if objects can be moved in a collaborative environment the collaboration gets more complex for the blind pupils in this kind of environment. The task becomes coordinating moving boxes rather than solving the math problem. Some added support is needed in order for the blind pupil to get awareness of changes. The handling of objects together and navigating is, however, not a problem in neither the Angle nor the Cube-moving environment.

2.8.2 Collaboration

The collaboration between the three pupils worked well in the Angle prototype and all groups managed to perform the task. The pupils explored and discussed each of the different angles and all pupils in the group were aware of each other and had a common ground through the whole work process. Verbal guiding was frequent, usually by the sighted pupils but in some instances the blind pupil was taking the initiative. In some cases the pupils did not agree on what kind of angle it was and had a long discussion about the distinction between them, regardless of if they had a visual impairment or not, and finally came to a conclusion. This fulfils the goal of the design, that the system should support good communication about concepts that are represented in such a way that all three pupils feel that they talk about the same thing. In the interviews the pupils reported that they felt that collaborating went well and all pupils thought that it was fun to collaborate like this.

In the Cube-moving prototype the collaboration was more problematic due to the problems addressed before regarding the fact that this environment was dynamic. Two groups managed to collaborate rather well whereas the sighted and the blind pupils in the other two groups rather worked in parallel processes than together. In the groups were the collaboration worked well the pupils made an extra effort to coordinate the joint activities and for example utilized the haptic guiding function and thus carried the cubes together. In the groups were collaboration did not occur the pupils had a problem with the fact that the blind pupil was not aware of the changes in the environment and sometimes destroyed the joint work accidentally. In most groups however, the actual solving of the math problem was in this case made jointly and verbally before the rearrangement of the cubes. Also, in the final part of the task all three pupils discussed the result until they agreed that it was the right solution. One can argue that the Cube-moving environment did not support awareness efficiently in all cases but that the actual problem solving was made jointly except for one group that did not manage to perform the task at all.

The conclusion that can be drawn is that the Angle prototype supports collaboration very well whereas the Cube-moving prototype is more problematic but has great potential. The pupils do use for example the haptic guiding function and the pupils in two groups discussed a lot during the whole work process. However, this result shows that the qualities of this type of learning environment do affect the dynamics in the group work very much. The technology can easily become a large obstacle instead of a supporting tool.

2.8.3 Support for learning

The Angle prototype proved to be a good environment for social learning about angles. An interesting result is that many of the pupils, both blind and sighted, report that they preferred this type of tool to the one they usually use in math. One blind pupil said that she usually used a rubber pad for learning angles and that she thought that the space available on it was too small and that she liked the feeling of the much larger haptic interface. All pupils thought that the Angle prototype was a very fun way of learning angles. One pupil thought that pupils that normally were not so motivated during math lessons probably would get more motivated if using this type of tool. All pupils discussed the angles and were exploring them together during the discussion. This result shows that both applications supported a shared work process and would hypothetically be a good tool for social learning in the sense learning in a dialogue with others.

Due to several problems with lack of awareness of changes in the Cube-moving prototype some groups did not achieve an optimal learning situation with this tool. Three groups managed to solve the task and in two of these groups all three pupils were involved in the process during the whole time. In one of the groups that solved the task, the blind pupil was involved in the beginning when solving the actual math problem but she failed to keep track of how the solution was realized in the interface. In the two groups that managed to involve everyone the pupils said that they thought that this tool was more fun than doing math in an ordinary math book. Pupils in these both groups also reported that they found it easier to understand the concept of area, when they could see the relation between the area of the cubes and how they could cover a cuboid area with cubes. One pupil said the following.

“It is easier to learn when one can place the cubes and see that they cover a certain area than if you just look at a picture in a book”

Another pupil reported the following.

“this would probably be useful at the building education in college”

Results like this make it clear that this type of haptic and dynamic interface supports constructive learning as well as social learning. It seams that the qualities that the touch modality has enhances what is the essence in constructive learning (Säljö, 2000).

2.8.4 Inclusion

The results show that the two prototypes differ a lot in how well all pupils were included in the group work process. In both prototypes the pupils felt a high degree of physical presence and they never doubted that they were all together in the same virtual environment. However, the awareness of movements was poor in especially the Cube-moving prototype. This made coordination difficult when trying to place cubes and aligning them at a specific area. One blind pupil reported the following.

“it is hard to know where the others are”

In some groups the pupils were not involved in a shared process and they said that they mostly all worked individually. The results are thus mixed, when the pupils really made an effort they could all be included but even groups that wanted to include all failed due to overwhelming difficulties with the lack of awareness.

The Angle prototype on the other hand supported inclusion very well. The blind pupil was actively taking part in the whole process and knew both what the others did, what was expected from her and how she could contribute to the solution. The groups were good at guiding each other in the interface and to maintain a shared focus through touch and vision respectively. The pupils reported that they felt that everyone worked together and that no one felt neglected.

The conclusion from this is that a shared work process can be obtained in these types of interfaces in which both blind and sighted pupils can form an understanding of the layout of the workspace. It is possible to discuss a math problem involving geometrical concepts together and use the shared interface in order to solve it in such a way that everyone feel that they are included. However, the design of the multimodal environment affects the level of inclusion in a powerful and yet subtle way, which makes it very important to have knowledge about how to design a truly inclusive environment.

2.9 Recommendations

A number of recommendations have been formulated in order to inform design of this type of collaborative learning tool for group work with blind and sighted pupils. The recommendations are the following:

1. Provide a shared workspace that looks and feels as the same space for both a sighted and a blind pupil.

2. An enclosed space with fixed objects makes it possible for blind and sighted pupils to form a shared stable mental representation of an environment, which is essential for successful collaboration.

3. If a collaborative environment has dynamic objects these have to stay where they are placed and should not be easily moved when a blind person explores them.

4. Physical guiding tools are very helpful in dynamic environments in order for the blind and sighted persons to move or explore objects together.

5. Lifting and moving an object is easy for a blind person to do in a haptic environment but stable target areas are needed when placing objects.

6. Provide feedback about changes in an environment that other persons make in order to get a general sense of awareness.

2.10 Discussion

In this study two applications were developed in order to support group work in the topic geometry in groups with visually impaired and sighted pupils. These applications were evaluated in schools by small groups of one visually impaired and two sighted pupils.

Results show that a shared virtual environment that has haptic feedback can provide a mental representation for both the visually impaired pupil and the sighted peers that make it possible for them to obtain a common ground during group work. However, the results also show that the design of a multimodal environment affects the level of inclusion in a powerful and yet subtle way. If certain aspects are not successfully designed like, for example, awareness information about changes in an environment the blind pupil might end up excluded from the work process. This makes it very important to have knowledge about how to design a truly inclusive environment in order for it to work properly.

A number of guidelines have been formulated in order to inform the design process when developing the technical platform in Work Package 4.

3 Supporting Cross-Modal Collaboration

Adding a Social Dimension to Accessibility

Royal Institute of Technology, KTH

This study has been reported in a previous deliverable on cross-modal equivalence (deliverable D4). In this text the implications from this study regarding collaboration will be discussed and guidelines for the design of collaborative applications will be suggested.

3.1 Background

Research on interfaces for blind users has mainly focused on single user interfaces, where one person interacts with a computer. Much focus has been on support for access to the *functionality* of the graphical user interface, providing the same means for *manipulating* the interface objects, support for *exploration* of the screen contents, and a representation that is *coherent* or similar in terms of completeness of the information presented, which objects are presented, how they can be manipulated, and the relationship between the objects (Mynatt, 1997).

Even though most researchers and practitioners today agree that collaboration is an integral part of everyday work practice, and that blind users in particular often work with sighted co-workers, studies that actually investigate collaboration are very few. Instead, it is sometimes assumed that *if* a non-visual interface is successful in enabling information manipulation, exploration and provides access to functionality in ways which are coherent, *then* effective collaboration can emerge as a natural benefit. That is, if the same relationships between manipulable interface elements are available to both sighted and blind users, then there are no barriers to effective collaboration (Mynatt, 1994, Petrie et al, 1995, Savidis et al, 1996, Wall and Brewster, 2006).

Previous research has however pointed out that an accessible single user interface does not necessarily imply support for collaboration (Winberg and Bowers, 2004), and it can even be detrimental to accessibility in a collaborative setting to strive for complete functional similarity (Winberg and Bowers, 2004, p340). What seems more important is to support the participation in a *working division of labour* where the blind user's work is integrated *in an accountable way through a collectively developed, negotiated and evolving knowledge and practice* (Hughes et al, 1992, p117). This means focusing not on the individual's ability to cope with all possible situations that may arise, but rather the group's ability to interdependently solve the task at hand, and make collective corrections when problems arise.

Designing alternative presentations for supporting cross-modal collaboration is a question of designing a presentation that *provides means to collaborate, solve problems, and participate in a way that is beneficial and meaningful for the group and for the individual*. This means that the alternative presentation should be sufficient to let the blind user take an active part in the collaboration and be part of the problem solving. The blind participant's work should also provide an important contribution to the group’s work, and the contribution should be meaningful for the individual as well.

Evaluating interfaces based on the above properties requires not only a conclusion that one interface works, or that one particular solution is better than another, but rather a qualitative understanding of *how collaboration takes place*, and what aspects in the interface that *makes collaboration at all possible*, hence the focus on a qualitative case study methodology rather than a traditional comparative experimental study.

3.2 Prototype Specification

The prototype used in the study described in this paper was designed to support drag and drop, which involves movement of objects by positioning a pointer on the object to be moved, picking it up, dragging it to the desired location and dropping it there. In order to do this, the interface must support getting an overview of all objects, locating a specific object, and interacting with that object. The prototype is a simplified version of the interaction common in graphical user interfaces, where a number of objects are located on a two dimensional workspace. The user interacts using a graphics tablet and a pair of headphones.

3.3 Sonification Model

3.3.1 Zoomed View

The zoomed view gives the user detailed information about a subset of the display, the quadrant in which the pointer is located. All objects placed in the same quadrant as the pointer are audible. The volume of each object depends on the distance to the pointer; the closer an object is, the higher the volume. The objects are presented one by one in a rapid sequence. This enables the user to get a quick overview of the whole workspace by quickly positioning the pointer in each quadrant and listening to the short sequence of objects (Figure 6).

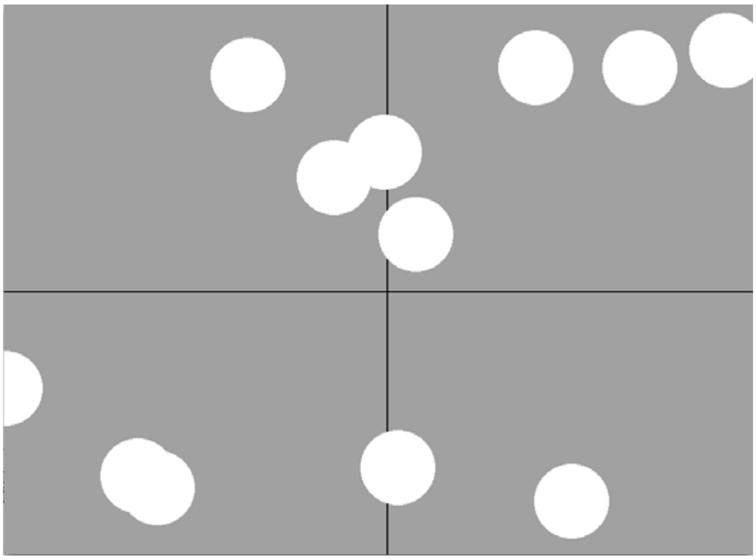

Figure 6. A graphical presentation of the auditory drag and drop prototype.

3.3.2 Objects

All objects have separate sounds. The sound changes depending on where the object is located with respect to the pointer. A guiding tone is added to the sound (a high, low or middle pitched tone representing above, below or at the same vertical level). The distance between the pointer and the object is presented in two different ways. The intensity (volume) of the object sound and the guide tone is mapped to distance; the closer the pointer is the louder these sounds will play. The guide tone has also a repeating pattern that changes with distance. The total time is always constant, but the number of repetitions increases when the distance decreases. This means that the closer the pointer gets to an object, the faster the guide tone will repeat itself.
The horizontal location is represented using stereo panning (left, right or middle representing left, right or the same horizontal level).

3.3.3 Interaction

The user interacts with the objects using a pen stylus on a graphics tablet. This is used in order to have absolute positioning of the pointer, as opposed to the mouse whose relative positioning makes it harder to use sound as the only output device when the complexity of the display is large (cf. Pitt and Edwards, 1995). Additionally, using the mouse requires sonification of the position of the cursor, which limits the auditory bandwidth left for sonifying other components (cf. Winberg and Hellström, 2001).

There are also event driven sounds that give the user feedback on specific actions, in order to emphasize the directness and physical nature of the interaction. These actions include hitting, picking up, dragging, and dropping an object.

3.3.3 Collaboration

For the purpose of using this prototype to study cross-modal collaboration, we added a graphical representation in order to have both an auditory and visual representation of the workspace (see Figure 6). Also, additional event driven sounds like the ones described above was added to support awareness of when the user of the visual interface picks up, drags and drops objects.

As described above the screen was divided into quadrants, and these were used to define two private workspaces. The auditory interface just showed the objects placed in the top-left and bottom-right quadrant, and the visual interface only showed the objects located in the top-right and bottom-left quadrant. The presentations were mutually exclusive, which means that there was no shared presentation at all, either you used an audio-only or a visual-only interface.

3.4 The Study

A collaborative study was performed, where one blind and one sighted person were to solve a number of tasks using this prototype. This study is a follow up study to the Towers of Hanoi collaboration study presented in (Winberg and Bowers, 2004). In the first study a limited interaction space was available for the users; only three discrete horizontal locations were used for interacting with the auditory interface. In the study presented here the users were able to move objects almost continuously in two dimension, and the question were whether the results from the first study would be valid when interacting with a more complex interaction space.

3.4.1 Setup

The subjects were sitting next to each other at a table, the blind subject with a pair of headphones and a graphics tablet, and the sighted with a small monitor and a regular computer mouse (see Figure 7 below). The sessions were video taped for later analysis.

3.4.2 Procedure

The subjects were given two different tasks, sorting and handover.

In the *sorting task* an unknown number of objects was randomly scattered on the workspace, and the goal was for the subjects to place an equal number of objects in each quadrant. This task focused on the interplay between individual perceptions of the objects placed in the private workspace, and the mutual agreement and coordination on what needed to be done to sort the objects. The subjects tried this with 8 and 12 objects.

In the *handover task* three objects were placed in separate quadrants, and the goal was to “move” the empty quadrant clockwise by moving the objects, until the empty quadrant had travelled four laps, while making sure that no quadrant ever contained more than one object. This task focused on the coordinated movement of objects and mutual understanding of an agreed strategy.

Figure 7. Two subjects solving the handover task. The sighted subject to the left and the blind subject to the right. The small screen at the bottom of the screen was present for monitoring purposes.

For both of these tasks the subjects were told what they had to do, and that solving the tasks required them to collaborate since they could not see or hear the objects located in the other subject’s private workspace. They were told they could move objects and drop them in the other’s workspace, but not picking up objects (by randomly clicking in areas they know objects are placed. When the subjects agreed that they were finished with a task they were supposed to tell the session leader about this.

The session ended with an informal interview with both subjects. In this interview issues like collaboration, what might have caused possible problems, the division of work, and possible changes to the software were discussed. General issues about inclusion were also asked, such as for example whether the blind subject contributed to the problem solving in a meaningful way and if the blind subject only followed the sighted subject's instructions.

3.4.3 Participants

Two pairs participated in this study; both pairs consisted of one blind and one sighted subject. The first pair consisted of one blind female, 45, with basic computer knowledge, and one sighted male, 37, with intermediate computer experience. The second pair consisted of one sighted female, 29, with intermediate computer knowledge, and one blind male, 30, with basic computer knowledge. The subjects were recruited both at the department (the sighted male and the sighted female) and via contacts from previous studies (the blind female and the blind male).

3.5 Results

The session was analysed using the recorded video from the sessions (see Figure 6 for a screen shot from one of the sessions). During the review of the recorded material specific attention was on how the subjects achieved a *working division of labour (*Hughes et al, 1992) when performing the tasks (cf. Winberg and Bowers, 2004).

3.5.1 Sorting Task

The sorting task involved two separate activities: establishing the total number of objects and re-distributing the objects.

To establish the total number of objects the subjects needed to count the number of objects placed in "their" quadrants, add them together, and decide how many objects that needed to be relocated. For the sighted subject this was an easy task and something that was done directly. For the blind subject this involved a bit more attention and took more time. This task was done interactively, which meant that the subjects were talking to each other throughout the whole process, discussing how to solve the problem. Even though it took the blind subject more time to get an overview of the quadrants and the sighted subject often had to wait for the blind subject to find out how many objects were located in the blind subject's quadrants, this was not experienced as a major problem by either participant in the post interview.

One thing that caused some initial confusion was when one or several objects were located at the border between two quadrants (as can be seen in Figure 5 above). For the user of the auditory interface an object was either located inside or outside, there was no representation of "on the border", as was the case in the visual interface. This led to an ambiguity when it was time to count the total number of objects since it was not clear whether an object that was in the border was audible or not for the blind user. After a while the subjects realized that the easiest way to deal with this situation was to simply grab these ambiguous objects and place them well within the boundaries of one quadrant. In the post interview this delay in clearing this ambiguity was partly explained by the fact that one of the sighted subjects initially was not sure that she could move any objects at all.

Re-distribution of the objects started when the subjects had agreed on a strategy, which in this case meant that they had decided that a certain number of objects should be re-located to another quadrant. This second part was done very quickly and without any delays. Both subjects had agreed what to do and the movement was done individually.

3.5.2 Handover Task

The handover task involved the same basic activities as the sorting task: establishing which quadrant was empty and movement of the objects to complete four laps.

Establishing which quadrant was empty was done quickly and no apparent difference between the subjects was noticeable, nor was this brought up in the post interview. Moving around required some afterthought. In order to "move" the empty quadrant clockwise the objects needed to be moved anticlockwise. After a few seconds of deliberation they all figured it out and started to move. The movement was accompanied by talk all the time, where both subjects were thinking aloud and announcing their moves, as well as acknowledging what the other one was doing. Occasionally one of the subjects would get lost and start to hesitate, but this was quickly alleviated by the other subject and the movement was picked up again. This momentary confusion happened to both subjects.

3.5.3 Collaborative Issues

The auditory interface made it possible for the blind subject to take part in the problem solving, both by *active inquiries* in the interface as well as *repairing breakdowns*.

The auditory interface made it possible for the blind subject to take part in the problem solving, both by *active inquiries* in the interface (exploration of the auditory space) as well as *repairing breakdowns* (realizing when an error has been made and taking the necessary steps to correct this). Interaction with the interface objects, albeit slower than for the sighted user, was unproblematic and did not cause problems for the collective problem solving. *Monitoring* the other person's actions was indirectly supported by the assembly of resources (Winberg and Bowers, 2004) provided by the manipulation in the interface and the social interaction. In these respects, the interface supports the blind subject participation in a *working division of labour* (cf. Hughes et al, 1992), where each participant at every instance has a job to do, as well as resources for monitoring the activities of the other participant. Also for both tasks the auditory presentation made it possible to *collaborate, solve problems,* and *participate* in a way that was *beneficial and meaningful for the group and the individual.*

3.6 Discussion

3.6.1 Accessibility

When talking about accessibility this is often thought of as something absolute and definite, either we have it or we do not. However, in the post interview one of the blind subjects expressed that even though he lacked the quick overview you get when using a visual interface and sometimes needed to ask the sighted subject about things, he thought that this prototype was fully accessible in the sense that he took part in the problem solving, and that an equal amount of work was done by both subjects. When asked further about this the subject said it did not matter so much as long as it made collaboration at all possible.

3.6.2 Design of Tasks

The main difference between the two tasks was that in the first case (sorting task) the focus was on getting a correct initial overview and the movement was secondary, whereas in the second case (handover task) taking momentary decisions and making the moves was in focus and the initial overview was secondary. In the first task the perceptual properties of the interface was the focus and in the second the problem solving (albeit on a quite low level). This led to a difference in the relationship between the sighted and the blind subject. Since getting a proper and exact overview takes more time for the blind subject, every instance where this is crucial will leave more time for the sighted subject to work with the actual problem solving, hence creating an imbalance in how the initiative shifted between the participants. This imbalance was present in the first task but not in the second.

This stresses the importance of the design of tasks. How the tasks are designed, and what resources are available, both through manipulating and getting feedback from the interface, and how verbal and non-verbal communication is supported, will not only influence the demands on the multi-modal system, but also to a great extent the division of labour.

3.6.3 The Importance of Context

The results emphasize the importance of acknowledging the context of use, which encompasses issues such as for example task, location, motivation and the experiences of the people interacting with the system. A fundamental concept like *accessibility* can involve different things depending on what contexts it is applied to, and more importantly an application that is believed to be accessible and to support collaboration in one context might not do so in another.

One crucial question is of course whether a study of an artificial task in a laboratory setting like the one described here really takes into consideration the different aspects of context outlined in the previous paragraph. Studying a real task *in situ* would of course yield the most relevant data *for that specific context*, but there are still good reasons to expect the basic issues of cross-modal collaboration to be present as long as the context includes collaboration of some sort that takes place in different modalities between participants of different abilities (cf. Winberg and Bowers, 2004, p339).

Future studies of cross-modal collaboration must take these issues into account, and also find a way to capture the specific context that is of interest, as well as the social interaction between the participants.

3.7 Recommendations

Based on the analysis and the previous discussion, the following recommendations are proposed for collaboration between blind and sighted users:

1. Provide support for both getting a quick overview of the shared or private workspace, and to get detailed information about a subset of the workspace.

2. Provide support for collaborative error recovery. This involves mutual understanding of how to solve a specific problem, and support for detecting deviations from the solution.

3. When designing support for collaboration focus on pragmatic and context specific accessibility which allows the blind participant to collaborate, solve problems, and participate in a way that is beneficial and meaningful for the group and for the individual. Functional or perceptual equivalence might not be necessary or even sufficient.

4. Design tasks that pre-empts possible imbalances in initiative, resources and perception. This involves studying the tool in context to find out possible problem areas and design to avoid this.

4 Collaborative Gesturing in a 'Describe and Draw' Environment

University of Glasgow, UGLAS

4.1 Introduction

Access to images and diagrams for visually impaired users is an unsolved problem. Screen readers are excellent for reading out text from the screen and navigating in a linear manner but browsing a diagram, chart or a simple drawing is an immensely difficult task for a visually impaired user. This section attempts to address some of the challenges through multiple forms of non-visual feedback. It will examine a 'describe and draw' task where two users can work together in order to build up an understanding of simple line diagram and describe techniques for maintaining an awareness and locating objects within the diagram as the user works.

A previous study conducted during the MICOLE project at Glasgow University examined shape perception issues when exploring a shape through haptic trajectory playback. This (described in detail in D6) demonstrated reasonable success for recreating shapes when played back through a force feedback device. An as yet unpublished study demonstrated how significant improvements could be achieved with the addition of auditory feedback to the trajectory playback. The authors were able to demonstrate over 80% correct gesture recognition using a multimodal approach with a 3-layer MLP neural net trained on sixteen gestures compared to 70% through haptic trajectory playback alone. The following work will exploit these results in combination with techniques from the literature to provide a system where one user can describe a tactile image to another.

4.2 Previous work

4.2.1 Tactile Diagrams

Traditional methods of accessing diagrams use raised paper technologies to present diagrams to users. These technologies raise 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 in most cases not sufficient to provide an accessible tactile diagram.

There have however been a number of attempts at addressing the problem of accessibility of tactile diagrams. As direct translation from the visual to the tactile tends to provide very inaccessible material, it is important ensure that any system developed to build or explore tactile images addresses the important issues that arise that are specific to presenting diagrams through touch. Eriksson (1999) describes several principles that are important when presenting student with a tactile picture. One key feature emphasised by Eriksson are 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 the user can build up a spatial representation of the image by allowing them to explore the relative position 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.

Kurze (2006) 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.

Wall and Brewster (2006) present a computer based system for accessing bar charts that shares many features with a raised paper diagram. The user moves around the image by moving a stylus over a touch pad 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 as 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 and Brewster (2006) describe a system that again exploits the computer based representation. They present a system that allows a user to explore a bar graph felt in negative relief through a 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 phantom cursor over the base of the graph.

4.2.2 Communication through Gestures

One key aspect of the study this prototype is the ability to allow one user to convey shape information to another user through gesture. Two notable closely related works are that by Graham and Argyle (1975) and Oakley (2003). Both performed diagram perception studies with a similar 'describe and draw' paradigm with sighted participants. Graham and Argyle studied empirically the effect that hand gestures had on the transmission of shape information. They examined participants describing complex abstract scenes using verbal description alone or verbal description and hand gesturing. Through independent rating of the closeness of the drawn pictures to the actual pictures, they were able to show significant improvements in communication when hand gesturing was allowed.

Similarly, Oakley [6] studied the effect of gesturing on transmission of shape information but through a collaborative computer system. Trajectory playback was additionally used in this study. Three conditions were examined. Firstly trajectory playback of the image and verbal communication only were allowed. This was achieved by hiding both users cursor during playback. The second condition examined visual playback combined with verbal description of the image. The participant drawing the image could see the describer's cursor as he/she was describing the image. Finally, a combined haptic, visual and verbal condition was also studied. The results suggested that visual only and visual/haptic conditions produced significantly better drawings than the haptic only condition although no significant differences were noticed between the visual only and the visual/haptic conditions. Oakley's results suggest that additional information to the haptic trajectory playback is important to understanding the image. Here, we attempt to compensate for the loss of visual feedback with the addition of tactile, speech, and non-speech audio feedback.

4.2.3 Rationale

Perception of and creation of tactile diagrams by visually impaired users is a complex task. This work will attempt to study some techniques for improving these processes by combining force, tactile, speech and non-speech audio feedback. Similarly to Oakley, the key research question will be does the addition of haptic trajectory playback to the environment significantly improve creation of an image? However, a visually impaired user will be creating the image with additional forms of feedback not present during Oakley's study.

Lack of access to non-textual information is a key factor faced by visually impaired participants when learning many subjects at school. This is particularly notable for subjects such as mathematics where shape perception is important for many of the core topics. Some key issues important to WP3 that are addressed in this work are collaborative learning, non-visual navigation of a 2D space and providing tools to help users to build up a spatial representation of objects in the environment. In this work, techniques from Oakley [6] and Eriksson [1] are combined to provide a prototype drawing system that allows two users to work together to interpret and build tactile images.

4.3 Prototype Specification

This prototype uses a similar bimanual interaction paradigm that proved successful for the Tactile Maze prototype (described in D6) and Wall and Brewster's bar chart system. The user will navigate by moving a device in the dominant hand while receiving tactile feedback cues to the non-dominant hand. In this instance, the user moves throughout the environment with the Phantom OMNI force feedback device from SensAble Technologies. Tactile feedback was presented to the user through the VTPlayer tactile mouse. Audio cues and speech were also used to aid navigation.

4.3.1 The Initial Prototype

The initial prototype was based around a simple gesture based game. Two users took the role of wizards that could cast spells at each other by gesturing using the Phantom. The goal of the game was to hit your opponent with spells. To cast a spell, the user gestured with the Phantom. The other user could feel and hear the gesture through trajectory playback and non-speech audio and was given the task of recreating the gesture to block the spell. However, many of the research questions that this game was developed to answer could be addressed through the computer taking the role of the second user. A single user gesture based evaluation of trajectory playback and audio was run with the initial evaluation described in D6. With the success of the gesture and audio based technique for conveying shape information, it was therefore decided that a more ambitious environment could be developed that encouraged collaboration. A collaborative 'describe and draw' based task was therefore developed to build on the single user gesture study results.

4.3.2 The Collaborative Drawing Environment

The drawing environment (shown in Figure 8) allows users to draw simple line drawings within a rectangular workspace like a pen on paper. It employs a similar two handed interaction mechanism that was used for the tactile maze (described in D6). The user navigates the environment using the Phantom while receiving tactile feedback through a tactile array in his or her non-dominant hand.

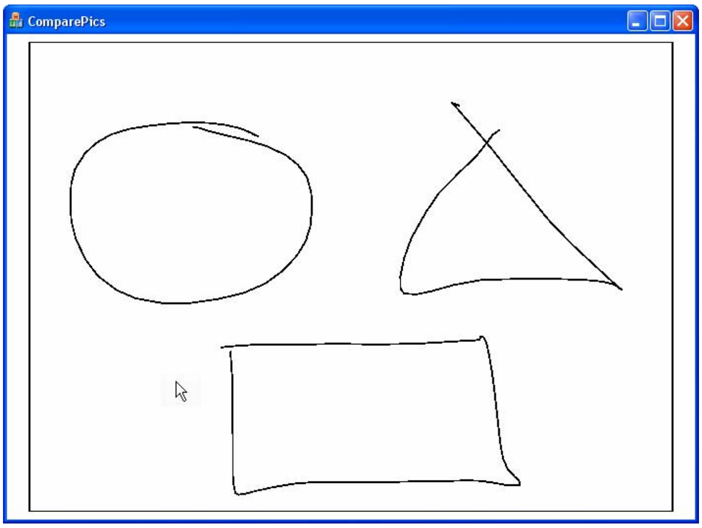

Figure 8. A screenshot from the drawing application showing the workspace, three drawn shapes and the user's cursor.

In the simplest case with no interactions other than moving through the workspace, the basic force feedback the user receives is very simple. The walls of the workspace are represented as stiff springs such that the user is constrained by the motors to a rectangular area inside the workspace boundaries. Through the tactile array, the user can feel the area immediately around the cursor (shown in Figure 9).

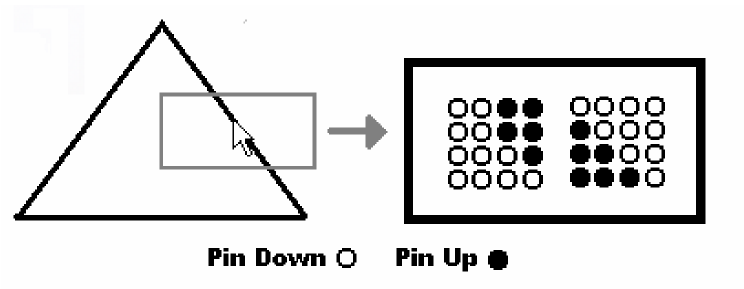

Figure 9. The user's cursor is shown over a triangle. The rectangular area around the cursor represents the area displayed by the VTPlayer mouse with the image on the right showing the corresponding VTPlayer display for this area of the image.

Two users can be present in the environment, and for the purposes of encouraging collaboration a teacher-student metaphor is adopted. We assign different roles to each user: one is the ‘describer’ and one is the ‘drawer’. The describer has some knowledge of what image is to be drawn (or is currently drawn) and the drawer draws the image. Both can interact with the environment but in different ways

The Drawer
The current feature set allows the user drawing the image to perform the following actions:

- Drawing – while the user holds button 1 on the Phantom and touches the paper, he/she can draw in the workspace like it were a pen and paper
- Text labelling & Speech playback – When the user finishes drawing and image and releases Phantom button 1, a dialog box is popped up allowing the user to enter a text label for the image. This is read out when the user enters the shape boundary while moving through the environment
- Locating objects – Users can cycle around the objects in the environment using the left and right arrow keys. The text label of the current object is read out as the user cycles through the parts of the drawing. The user can press and hold the down arrow to read out the text label associated with the current object. Further, the user can hold down the down arrow along with Phantom button 2 to be dragged by the Phantom to the object’s location.
- Shape playback – A user can playback the trajectory of the currently selected shape by pressing button two on the Phantom while inside the shape boundaries.
- Pausing the phantom position – The user can stick the Phantom position to the current position by pressing space bar. This allows the user to rest his or her arm while maintain his or her position in the environment.
- Audio positional cues – Non-speech audio cues are used to alert users to their position within the environment. The left/horizontal position is mapped to audio pan while the vertical position is mapped to the pitch of the audio.

The Describer
The describer can traverse the image like the drawer. However, they can also directly interact with the drawer by grabbing the drawer’s cursor and dragging it through a path. It is envisaged that this will be used to aid the user to describe a shape to the drawer.

4.3.3 Scenario of Use

This prototype is envisaged to be used by two users in different roles. One user acts as the teacher and may or may not be visually impaired. This user has some knowledge about a diagram that they must convey to the other user. The other user has no previous exposure to the diagram and must convey the pictorial information through words and gesture.

4.4 Evaluation

4.4.1 Method

An initial evaluation was carried out at the Royal National College (RNC) in Hereford in the UK. Although this prototype builds from previous MICOLE work carried out at Glasgow University in trajectory playback, this was the first attempt at integrating the techniques into a functional application. At this stage, it was therefore important to test all the features of the interface to determine whether they were usable and useful in an application context. This was achieved through an observational study.

Three groups of two participants took part in the study. Two of the groups consisted of participants from the RNC, and the third group consisted of one participant from the RNC and one participant from Glasgow University. In each case, the describer was either sighted or had a lot of residual vision, and the drawer was visually impaired with little or no residual vision. Figure 10 shows the drawings used in the study. Drawing A contains simple and easy to describe shapes and was used to introduce users to the system. Drawings B and C contain more complex shapes with the relative positions of some of the shapes becoming more important.

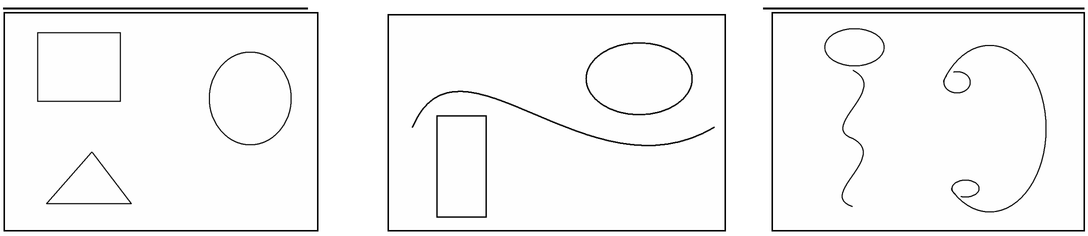

Figure 10. Three line drawings used in the study A (left), B (middle), C (right). A was used to introduce users to the task and contained simple easy to describe images. B and C contained more complex lines that were more difficult to describe verbally.

All interface features were described to participants, and a number of tasks were set. The three line drawings from Figure 10 were given to the describer on paper with the goal of the task being for the drawer to use the software to create a representation of the paper drawings on the system. The methods used for this study were left to the participants to discuss. Participants were encouraged to discuss the drawings and their actions throughout the study. They were then observed solving the tasks using the interface features that they felt were appropriate. Video and audio recordings were then examined *post hoc* to determine the situations in which the various interface features were useful.

From the point of view of collaboration, the interface feature that was of interest was the playback feature that allowed the describer to drag the drawer around a shape.

Observations were made about when this feature was felt to be necessary to describe a shape and how it was used. Verbal communication between the users was also closely observed.

4.5 Results

Through observation it became clear that the playback feature was useful in some instances but not in all. When the shapes being drawn could be named, verbal description was used in the vast majority of situations. This was the case when describing the shape, size and position of the object within the diagram.

For drawing A, the playback functionality was not used by any of the participants. Each shape was easily nameable, and no fine grain positioning was required. The describer simply stated, *"draw a circle"* or *"draw a triangle with the point at the top"*. Verbal guidance was used to position the objects within the scene. This took the form in all cases of dividing the scene into top, middle and bottom in the vertical and left, middle and right in the horizontal. The drawer seemed comfortable positioning themselves within the environment using these terms. The wall forces were used to build a frame of reference and the Phantom interactions allowed absolute position to be estimated from the proximity to the walls.

When shapes were not easily verbally describable like in drawings B and C, the haptic playback became an important tool. Figures 11 and 12 show the final drawings for all 3 groups of participants for drawings B and C respectively. In all instances all the shapes are included in the final drawings with appropriate relative positions. For all parts of these drawings, the playback mechanism was used to describe the shapes except for the oval in the top left of diagram C. In two instances, the describer related this oval to the oval felt in drawing B and did not have to redraw it to describe it again.

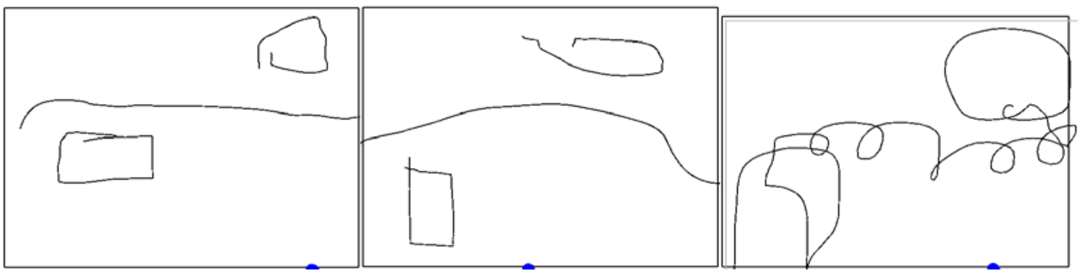

Figure 11. The results from the 3 groups when attempting to draw diagram B

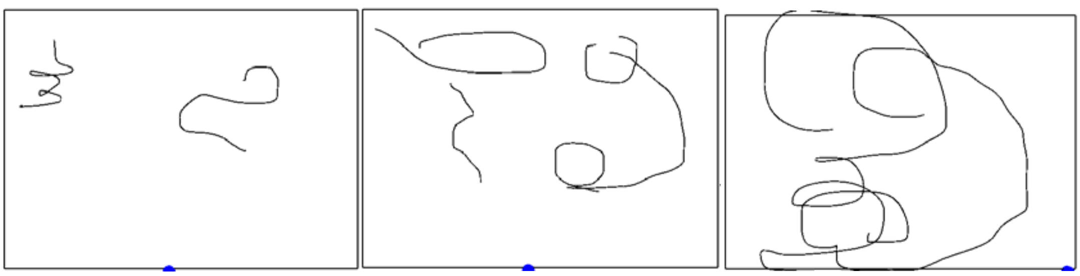

Figure 12. The results from the 3 groups when attempting to draw diagram C

Trajectory playback was utilised in two different circumstances: sometimes instigated by the describer and sometimes by the drawer.

When instigated by the describer, in some instances it was due to being unable to describe the shape. In the other instances (and more commonly) it was due to a description not conveying the appropriate information. The describer describes the shape and the drawer interprets it wrongly. The describer then used the haptic playback as a different means of conveying information about the shape. One example for the right hand shape of diagram B is where a describer said *"It's a bit like headphones on its side. I'll draw it"*. After getting pulled around the shape and no further verbal description, the drawer replied *"I can feel that. It was like headphones on its side. Like a semi circle going to the right with two little circles on the end of it"*. Here, the describer notices the difficulty in verbally describing the shape and draws it. The drawer uses the playback to form a clearer mental picture and relates it to the original verbal description given.

When instigated by the drawer, it was in used when the drawer found the verbal description difficult to understand. In some instances, the drawer would make an attempt to draw the image and not get close to the correct shape. The drawer would then request that the describer draw the image for them. This was used to great success in some instances where the drawer was then able to describe the shape to the describer through what they felt. For the left hand shape of drawing C, one describer described it as *"This one is a wee bit strange. There's a circle on the end and it's got a squiggle coming from it"*. After some unsuccessful attempts to describe the shape further, the drawer asked how it felt. The drawer felt the shape and replied *"Like a balloon on a bit of string"*

In all instances, verbal communication was used initially to describe the shape with the drawing functionality supporting the verbal communication. A common technique was to compare the shape to a similar object like a wave, a pair of headphones, a balloon on a string, or a door. This provided a starting point for the discussion about the shape with the drawing tool being used to describe difficult sections of the image or clear up misunderstandings.

4.5.1 Other Observational Results

One novel use of the playback system was to direct the drawer to the appropriate area of the canvas to start drawing. Instead of drawing a shape, the describer tapped the draw button which moved the drawer towards the starting point. This was used in particular where fine grain relative positioning of the objects was important.

The playback system was useful for this task although this study suggests that a number of improvements could be made. Here, the describer would draw the shape and when completed, the drawer would be dragged around it. This made multimodal communication difficult. The describer could not talk the drawer through the shape as they were drawing it since the drawer would not feel the shape until the describer had finished. Furthermore, the trajectory was played back at the same speed independent of the speed of movement of the drawer. This lead to problems in difficult areas of a shape, where the describer might want to feel slower movements to gain a better understanding of the detail of the shape.

The drawers suggested that the audio positional cues were largely unused. Although this feature was popular in a drawing environment with one user and was shown to provide benefit, all three drawers mentioned that they were concentrating on the haptics and were not using the audio. One possibility is that verbal communication interferes with the audio positioning cues. The drawer is listening to or talking to their partner and may pay less attention to the audio cues as a result.

4.6 Discussion

The above results suggest that the collaborative feature of the drawing interface could be used to describe a diagram to a visually impaired user. Particularly for complex shapes, the haptic playback feature complemented the verbal communication to lead to a better understanding of the shapes. Both the describer and the drawer found the playback a useful technique; the describer when they found it difficult to describe a shape in words (or the drawer misunderstood the verbal description) and the drawer when they did not understand the initial verbal description.

However, the form of the haptic playback affects how the collaboration can take place. By only allowing playback after the describer had completed a trajectory, the potential for combining haptic information with a simultaneous verbal description was lost. This is one area that should be addressed when studying the quality of information transferred through the haptic playback. Speed of playback is another issue. It is unknown how changing the speed of playback will affect the ability to create a mental image of a shape. Participants reported however that difficult areas of a shape might be easier to understand if felt slower.

4.7 Recommendations

The following recommendations for environments allowing collaboration between sighted and blind users can be drawn from this study:

- Trajectory playback with a haptic device can successfully be used to complement a verbal description when describing a trajectory or shape information for complex shapes.

- An environment containing trajectory playback should allow real time interaction between the participants such that users can discuss their movements as they move the other user through the environments.

- The rate of playback should be adjustable to allow the user to slow down for detailed areas of the trajectory if required.

4.8 Conclusions

This section has described an interface that uses cross modal techniques for allowing a visually impaired and a sighted user to browse and create drawings. A study has been described that test the usefulness of the interface for a sighted user describing shapes to a visually impaired user. From this study, it can be concluded that haptic playback can play an important role in collaboration between a blind and sighted user.

Future evaluations will be carried out to gain a more quantitative understanding of the effect of trajectory playback in communicate shape information to visually impaired users. This will be achieved with a two condition study. In one condition, the users will be restricted to verbal communication only and in the other, they will have the option to use trajectory playback as well as verbal communication. Through this, more understanding will be gained of the role that haptic trajectory playback can play in a collaborative task.

5 Two-Handed Navigation in a Collaborative Haptic Virtual Environment

University of Glasgow, UGLAS

5.1 Introduction

Users rely heavily on visual feedback when interacting with a computer whether working alone or collaborating with a colleague. However, computer users with no or very little vision must rely on other modalities to access the same information. Screen readers have proved to be a successful solution for accessing the textual information required to interact with a computer. However, this information is generally accessible only in a linear manner (from the top left corner of the screen) and non-text information such as pictures and diagrams are not easily displayed in this manner. The goal of this work is to examine techniques to enable multiple users to navigate the same computer interface and explore and share information non-visually in a non-linear manner. To achieve this, a two-handed focus-context interaction paradigm is adopted. Users can navigate a cursor in a 2D space and receive force-feedback by moving a device with their dominant hand. They also receive contextual information through their non-dominant hand. The contextual information in this case will be directional information displayed on a small pin array.

One key aspect - particularly when considering applications designed for children – is developing tools to aid collaboration of more than one user in the same environment. This may be to support two children working on a project or playing together, or potentially a teacher working with a child to explain some concept. Here we must ensure that our environments support methods of providing awareness not just of the data that the users are browsing, but also awareness of other the users within the environment. The task becomes more complex when we consider that more than one ser can change the environment. The data must now be considered dynamic for each user if we consider that other users can alter the data.

5.2 Background

5.2.1 Bimanual interaction

Similar bi-manual techniques have previously proved successful for accessing information non-visually. The Optacon (1970) is one commercially available example. Visually impaired users could access printed material by moving a camera over a page with one hand while receiving a vibrotactile representation of the image under the camera presented to the other hand. Recently, Wall and Brewster (2006) developed a system for browsing a bar chart with a graphics tablet and stylus for navigation. The fixed frame of reference offered by the tablet allowed users to employ their proprioceptive sense to maintain an idea of where they were within the environment. In the non-dominant hand a direct tactile analogue of the graphics was presented to the users' finger tips allowing them to browse the data through a small tactile window centred around the current cursor position.

5.2.2 Tactile Directional Cueing

Tactile cueing has previously been studied, for example, by van Erp and van Veen (2003), who used vibrotactile cues spatially distributed around a user's torso presented through a tactile vest. Here, they use tactile patterns to indicate to astronauts their orientation with respect to the International Space Station. A recent study conducted by Pietrzak *et al.* (2006) examines the discriminability of different forms of cues presented to a user's fingertip through a raised pin tactile array. They examine the success of presenting a set of 8 different directional messages through different patterns of tactile cue. Different forms of static, dynamic, and 'blinking' (cycling between the pattern and an empty array) patterns are studied with the best performance noted with the static cues.

5.2.3 Haptic Collaboration and Communication

There have been relatively few studies examining haptic collaboration and communication for remote or computer environments. The aim of several of theses studies is to examine how haptics can be used to increase awareness of others in a shared environment. For example, Oakley (2003) explores the effect of haptic cues on the perceived presence and performance of users working in a shared environment. Oakley developed haptic cues that allow users to feel the cursor of the other user as a solid sphere. Further awareness cues were presented as a viscous force effect as two users became close together in the environment which became stronger and more noticeable as the two users became closer. Users may also feel a force that locates them to the other user within the environment by actively dragging the user's hand towards the other user's cursor. Finally, a user may drag another through a complex trajectory. Oakley demonstrates how these features work together to allow users to work together in a shared environment with a greater sense of awareness of other users. Sallnäs (2003) again examines task performance and perceived presence in a collaborative environment in an object manipulation task. The task set to users was to collaborate to move and stack boxes within the virtual environment. Sallnäs tested the task both with and without haptic feedback and were able to demonstrate significant improvements in performance (and perceived performance), as well as an increased sense of presence during the task. Fogg et al. (1998) describe HandJive which is a further example of a haptic collaborative environment. These devices are designed as a tool to support a person's desire to fidget. A single device is constructed of two moveable cylinders with the possibility of the device being paired with another HandJive. The user can manipulate a cylinder into several discrete positions with this movement being reflected on the other device. It is only possible to move the cylinders through the full range of motion through collaboration with the other user. The authors suggest that users could synchronize their movements to construct simple dances, or transmit haptic messages to each other through the devices.

In this section a multimodal non-visual navigation environment is described that allows two users to user their sense of touch and hear to compete against each other in a navigation task.

5.3 Research Goals

To provide a successful non-visual collaborative environment, the challenges involved will be:

- Supporting the ability to browse and navigate the data in the environment
- Supporting awareness of the other users in the environment
- Supporting awareness of changes in the environment due to other users.

The goal of this work is to investigate solutions to these problems using combinations of force, tactile and audio feedback.

This work addresses a number of issues identified during WP 3 requirements. Firstly, due the fact the environment is built as a game, it addresses a social need by providing an environment where blind users can participate in games. The fact that a game environment has been chosen should not restrict the same techniques being applicable to a broader range of applications. Usability testing with children can be particularly challenging as traditional tests with repetitive actions can seem boring to the children. The game environment encourages them to continue to use the system and test the techniques.

The main aim of this application is to study non-visual methods of aiding navigation and remote awareness. The directional cues developed for this study have been demonstrated to be successful in a single person maze environment and the challenge is now to expand the context of use to multiple users and multiple different shared environments.

5.4 Prototype Specification

5.4.1 The Collaborative Maze Environment

A single user maze environment to support navigation through a complex space was developed to evaluate this two-handed interaction technique for WP2. This environment has been described in detail in deliverable D6. The environment has now been expanded to incorporate more than one user within the environment. A screen shot of the application is shown in Figure 13.

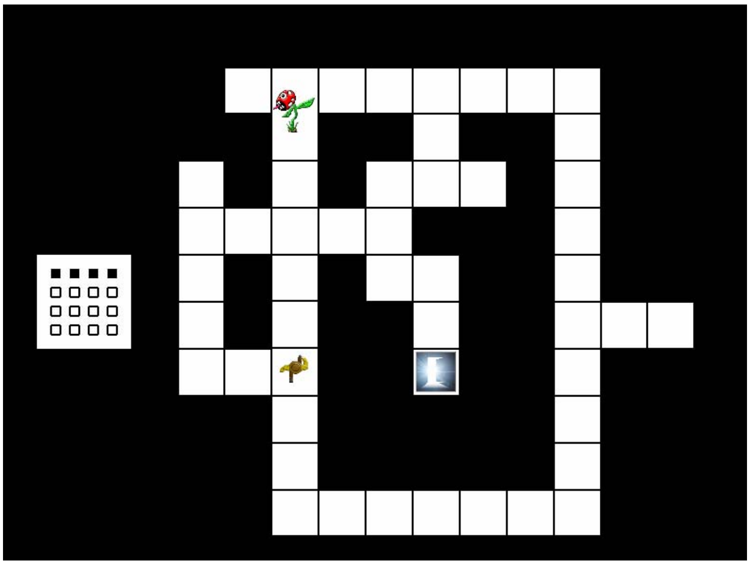

Figure 13. The maze application. One user must navigate the hero through the maze avoiding the monster. The other controls the monster and must find the hero before he reaches the exit.

The black squares represent walls, the white squares represent corridors. Two (or more) users compete against each other in the environment with two roles being present. One user must navigate the environment to reach the exit. The others must stop that user from reaching the exit.

Equipment

To interact with the system, each user must have access to a computer that is networked to the other. Use of the standard UDP protocol ensures that any two machines on the same network (even connect through Bluetooth) can run the game. For interacting with the maze environment, each user requires a PHANTOM force feedback device, a tactile display (in this case the VTPlayer tactile mouse), and a set of speakers or headphones.

Interactions

A user moves the sprite through the maze by moving the Phantom device with their dominant hand. The maze is set in the vertical plane. Users can move freely in the x and y plane but are tightly constrained in the z direction allowing for two degrees of freedom of movement only. The application will allow users to freely navigate the corridor while using a spring force to constrain the user to the path while pressing against a wall. The absolute position of the Phantom end-effector is directly related to the user's position in the maze allowing for absolute position judgments. Colours for the maze have deliberately been chosen to be high contrast to provide users with low vision to view the application.

Guidance in the form of directional information is provided to the user's non-dominant hand through tactile cues from the VT Player mouse. The user places fingertips on the tactile arrays of the mouse and is provided with information about the direction they must travel in to reach the exit. Different designs of cue were evaluated, for WP2. The results of these evaluations were described in D6. The collaborative environment can se either the static or dynamic cues described in D6.

Awareness of the other User

The users are made aware of the other users in the environment using audio and tactile feedback. Each user has a sound associated with their avatar that can be heard by the other user when close by. The volume of this sound varies as the distance between the users. Audio panning is also used to provide some directional cueing. If one user hears the other through the left speaker only, the other user is to the left of them. Tactile cues are also used to provide awareness cues of the other user but the cues provided depend on the user role. The user playing the monster receives more direct tactile feedback guiding them to the other user. These cues provide directional and distance cues to the other user. The user avoiding the monster must infer the monster position from the tactile cues as these cues will always guide him away from the monster and towards the exit. When the users meet in the maze, they are alerted with a vibrating tactile signal combined with complementary audio and speech feedback indicating that the hunter has one the game.

Timing Information

Audio is used to display the timing information. The user will hear a series of ticks with the length of time between the ticks indicating the amount of time left. As the ticks become closer and closer together, there is less and less time to complete the maze. A warning clock sound indicates that the user's time is nearly finished with 3 seconds left.

Basic Game Administration

There are a number of other tasks that must be performed such that the user can use the game with no visual feedback. Firstly, instructions on the goal of the game and how to start the game are displayed through audio. At the end of each game, a Phantom force effect pulls the users back to their respective starting positions at opposite ends of the maze for the next game. This force effect constrains the users to the start position until the game is started by clicking the Phantom button. A random number generator is used to randomly select a maze.

Displaying the Results

At the end of a game, speech is used to alert the user to the success or failure.

5.4.2 Navigation

To navigate the maze, the user interacts with a PHANTOM OMNI force-feedback device (from SensAble Technologies) using their dominant hand. This device offers high fidelity feedback while still being relatively cheap. The device has a small wrist movement sized workspace (160mm x 120mm x 70mm) and is relatively easy to overpower, which are both important safety concerns when the device arm can move independently and users cannot see the arm. Although this device allows 3D interactions, for the maze environment users are constrained by the device to 2D interactions in the vertical plane only. Users are always constrained to the corridors of the maze and can feel the maze walls (represented as stiff springs).

5.4.3 Tactile Cues

Directional Cues

Similarly to the single user maze, coded tactile representations were developed to aid user navigation. The information presented to the user was reduced to four tactile cues that provided the user the direction to the maze exit. These cues (presented on a 4x4 raised pin display) indicated to users that to get to the exit, they must move up, down, left or right. Two forms of these cues were developed: static and dynamic.

Static cues form a tactile pattern on the display with the pattern indicating the direction to move in. The four patterns are chosen to be similar to those developed in [4]. These patterns are shown in figure 14. Each pattern is represented by a line of raised pins on the display. The position and orientation of the pins indicates the direction the user must move in to reach their goal – the exit for one player (the hero) and the hero for the other player (the monster). If the raised pins are felt at the top of the display, the user must move up, and similarly for the other three directions. The pattern displayed remains the same until the user is required to change direction.

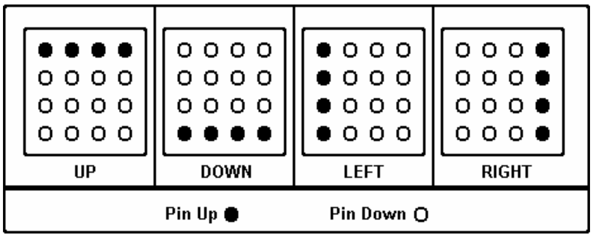

Figure 14. The four static cues used in the environment

The second set of cues (dynamic cues) use tactile flow to indicate direction. These offer the potential to be more expressive than the static cues as the rate of change of pins and changing patterns can now be altered to provide more information to the user. However, they may also be more difficult for the user to interpret [4]. A series of patterns is played to the user for each of the 4 dynamic cue messages. These patterns are shown in Figure 15. For each direction message, the user is played a series of five patterns where the direction of flow of the raised pins indicates the direction in which the user must move to reach the goal. In each case, the first and final patterns are left with no raised pins to allow the user to more easily separate the cues. Unlike in the static condition, the state of the display is constantly changing even when the user remains stationary. In the event of a required change in direction, the appropriate tactile cue is played from the start (always starting with an empty array). The rate of change of the display was chosen empirically at 100ms per update.

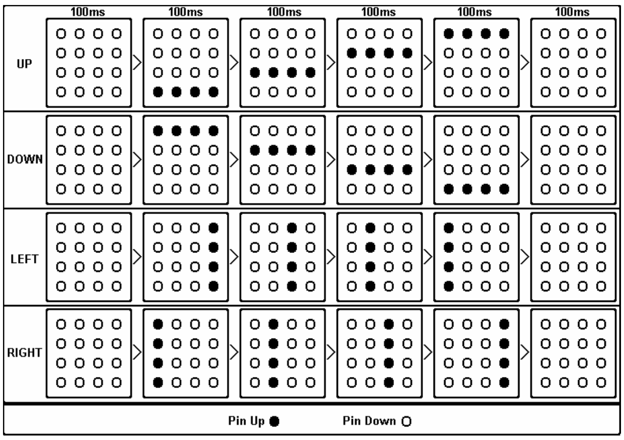

Figure 15. The four dynamic tactile cues used in the environment. Each row represents a series of patterns played to the user (at a rate of 10 patterns a second) to indicate a direction.

Contextual Cues

Unlike the one person version of the game, additional contextual cues have been incorporated into the environment. The second tactile display on the VTPlayer mouse is now used to display information about possible directions the user can move in. The cues are shown in Figure 16.

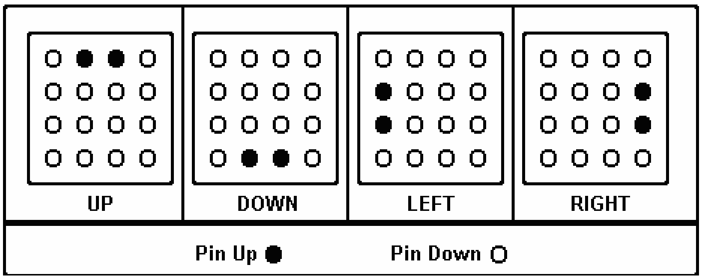

Figure 16. Contextual cues used in the environment. They are presented through a tactile array on the VTPlayer mouse to the user's middle finger

As there is potentially more than one direction of movement, the cues have been designed such that multiple cues can be presented on the same array without overlapping. Figure 17 shows the situation when the user can move left, right and up and the corresponding cue presented to the user. In the game environment, it might be used by one player to notice corridors they are passing without pressing into the walls.

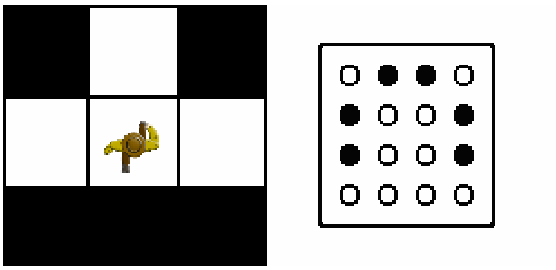

Figure 17. A combination of contextual cues are presented to the user as they pass a junction in the maze.

As there is potential for confusion when interpreting tactile feedback presented to more than one finger at any one time, it is envisaged that the contextual cues will be used sparingly by users. One advantage of the use of static cues notice during the single person study described in D6 is that users can be alerted to a decision merely by registering a change in the cue and not necessarily initially interpreting the cue itself. The use of static cues for providing context will allow users to focus on the more important directional cues and only switch attention to the contextual cues when a change is detected.

Scenario of Use

The prototype has been designed as a competitive game. It is envisioned that users will play the game either co-located in the same room or in separate locals. The game will assign alternative roles to each of the users in each game and randomly select the a maze environment from a selection of pre-created mazes.

5.5 Discussion

In this section three research goals were stated. In developing the prototype, functionality has been provided to support each of the three goals. These were:

- **Supporting the ability to browse and navigate the data in the environment** -Users feel wall forces from the phantom and get context information about the area around them through tactile cues representing possible movement directions

- **Supporting awareness of the other users in the environment -**Audio cues and information from dynamics and static tactile directional cues alert users to the presence of other users within the environment.

- **Supporting awareness of changes in the environment due to other users -** Here the important data presented to the user is the safe direction to their goal for the hero. As the users move, this can change as one path gets blocked or another opens. Users can interpret the changes in these cues as changes to the environment caused by the other user.

However, in order identify whether the features add value by supporting browsing behaviour and aiding navigation, a formal evaluation is required.

5.6 Future Evaluation

Two options exist for evaluation. Firstly an observational study of two users playing in a competitive environment could be used to gain a better understanding of what features of the system are providing benefit. In the single user maze, tactile cues were shown to be successful in guiding a user to a goal. However, it is important to take account of the dynamic nature of the two user environment. The direction to the goal will shift as the other user moves though the environment. By adding or removing features such as the contextual cues, an understanding can be gained about how each of the navigational features will be beneficial to the task. The competitive aspect of the game would allow techniques to be tested while maintaining the interest of the user. This is particularly important if the participants are children.

A collaborative system could equally well be used to test the navigational cues. Here the users would seek out paired objects in the environment. For examples, the users must locate two audio beacons within the environment. Once both had found the appropriate object, the goal would shift to locating each other in the environment. Awareness of the location of the other user in the environment could be explored through the use of the tactile directional cues. The user's spatial understanding of the environment is also an important measure. Will the users be able to learn the environment through the cues presented? This could be tested by repeated traversal of the same path.

6 Collaboration Study of Two Children Using the Space Application

University of Tampere (UTA)

6.1 Introduction

In part of the MICOLE-project a series of tests were conducted focusing on collaboration of visually impaired and sighted child using a space application. The application is designed for a single user and we wanted to investigate if it can be used also together. Four pairs of children (each pair composed of 1 visually impaired and 1 sighted child) were invited to use the system and complete some small tasks in a usability laboratory where the testing was observed and videotaped. Our tests are planned to be analysed more in depth later but in this phase some initial observations from the video recordings and the interviews will be reported.

6.2 Research questions

The space application has earlier (in January 2006) been tested with one user at a time for usability issues. This time we aim to get knowledge about its usefulness for collaboration support in MICOLE. The research questions are:

1. How does the space application with one Phantom device suit for visually impaired and sighted child's collaborative exploring?

   a. What kind of expressions of collaborative activities can be found?
   b. Were both children active in exploring the environment?
   c. Were both children active in solving the given tasks?

2. How should the application be developed to become more suitable for visually impaired and sighted children's collaborative exploring?

6.3 The Study

The study was conducted in UTA in collaboration with KTH. The pre-pilot test was planned and conducted by three researchers from UTA and one researcher from KTH. That meeting turned a very efficient and productive workshop between partners. In UTA three persons in all were involved in planning and conducting the tests and one of them in analysing them.

According to the experiences from the pre-pilot test the testing procedure and schedule was planned and documentation (in Finnish) was written. With help of the Jyväskylä School for Visually Impaired the invitations were sent to the families to participate to the tests and in May 2006 four tests were conducted in a usability laboratory of the University of Tampere where the set-up was built. The set-up consisted of equipment and furniture needed when two children were using the application together. The evaluation plan was written (in English) and according to that plan the tests were initially analyzed from video recordings.

6.3.1 Testing procedure

The tests were planned adapting the procedure and methods that were developed in our earlier projects where one child was testing an application. The procedure is particularly designed for visually impaired children when testing multimodal applications. Now we had a visually impaired child and a sighted child together using the application, which required some modifications to the testing procedure. Test situations were videotaped for later analysis of the data. The test was comprised of the following parts:

1. Start-up interview (children together)
2. Introduction of the application.
3. Teaching to use the Menu of the application with a real world model and a plastic stick
4. Teaching both children to operate the device
5. Using the application and device independently together
6. Completing together three tasks given by the test assistant
7. Questions and final interview of the children (children together)
8. Asking the children to plan together what to tell to the parent about the application
9. Children together tell the parent about the application
10. Interview of the parent

The test began with casual start-up interview concerning the children's experiences on computers and applications and possible earlier tests with a Phantom device. This way the children were accustomed to the test situation and to the assistant. They were then interviewed about group works at school. Then the children were shortly briefed on the contents of the application. The menu of the application (the Space Station) was introduced by means of a real world model. They explored the model first by hands and then they were taught to navigate the menu with a plastic stick (Figure 18). It was explained that with the device the exploration happens with the aid of a similar stick. Introduction of the menu was followed by teaching to operate the stylus of the Phantom in the correct position.

In these tests the children were first encouraged to explore the application freely (Figure 19). Guidance of any kind, both verbal and operational, was avoided as much as possible. After the independent exploring they were asked to complete three tasks with a help of the application.

Figure 18. A child is exploring the real world model of menu with plastic stick

The tasks were given one by one and the children told the solution to the assistant when they were finished with each of them.
The tasks were:

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?

Figure 19. Children exploring the application.

After completing these three tasks the children were asked a set of questions concerning the application and the collaboration. For example, they were asked about the sounds and haptic feedbacks in the application and about using the application together.

6.3.2 Test subjects

Altogether four 9 to 12 years old visually impaired children and four sighted children also 9 to 12 years old were participated in the tests of Space application and Phantom device. Three of the blind children were visually impaired by birth and one of them had gone blind later.

Three of the visually impaired children were boys and one of them was a girl. One visually impaired child was familiar with the device and the testing situation since she/he had formerly participated in Phantom tests carried out in the university projects.

The relationships of the visually impaired and the sighted child were different in every pair: they were siblings (two pairs), twins (one pair of the siblings), cousins (one pair) and friends (one pair). This is important to keep in mind when analysing the collaboration of the pairs. For example the twins were accustomed to do things together and the sighted child guided the visually impaired one very naturally.

6.3.3 Laboratory, device and set-up

The laboratory was comprised of two rooms. In the testing room the children operated the application and the device with the aid of the assistant who was a nursery school teacher. In the control room the child's parents and two test organizers were observing the test situation through a semi-transparent mirror.

As the haptic device we used a Phantom device for child to feel the contents of the application. In a Phatom, a stylus that is used like a pen is attached in the robotic arm that simulates the feel of touch. As another input device we used a Magellan space mouse. In this mouse there is a one large handle and four smaller buttons. Only the large handle was used in the test.

The visual feedback was provided with a 17" LCD monitor. Stereo audio was provided with loudspeakers.

The Phantom was placed in front of the visually impaired child and the LCD display in front of the sighted child (Figure 20). The computer for assistant was placed on the right-hand side of the children. With the computer the assistant managed the starting or when needed booting of the application. In addition, in some parts of the application the assistant changed the mode of the application by clicking options at the right moment. This added a minor Wizard of Oz effect in testing, and it was not noticeable for the user. The video camera took footage from right-hand side of the children.

Figure 20. The testing set-up was built up in the laboratory.

6.3.4 Application

The Space application is designed to support children's explorative learning (Kangassalo et al, 2005). That is why there are no predefined tasks or specific paths to follow. Children can navigate the application at will, according to their desire for knowledge. The application is planned to include particular agents among others for tracing user's locations and actions. This time it was tested partly without them because of some stability issues of the agent system. The parts of the application that were tested were "The Earth", "The Solar System", "The Bowels of the Earth", "The Orbit of the Earth" and the "Space Station" (the menu).

6.4 Results

This initial analysis is mainly concerned with the research question 1: How does the Space application with one Phantom device suit for visually impaired and sighted children's collaborative exploring? Some recommendations for the further development will be given in chapter 5 as well.

6.4.1 Observations from the use situations

All the pairs managed to use the application together. There were yet differences in degree of the collaboration. It appeared that both the social and the working skills of the children and also the closeness of their relationship influence how much they can collaborate.

The dominance in collaboration seems to depend on the Phantom user. The child grasping a Phantom stylus can dominate the other one who has no input device at all. Most of times the visually impaired child held the stylus and could then decide if or if not to take into consideration opinions and suggestions of the other child.

The roles of the children were similar in all of the pairs: The sighted child guided the visually impaired one to navigate in application telling him/her which direction to move and the visually impaired child used the Phantom stylus. But when the sighted child had his/her turn and she/he was using the stylus the blind child could also give advices to him/her. That happened when the blind child had first explored the environment with stylus and was thus familiar with the environment. The visually impaired child could give for example such advice as "press down over the planet" (in Solar System) or "go to the floor" (in Space Station). The Magellan space mouse (for getting back to the Space station – the menu) was used mainly by the sighted child. Only in one pair's using situation (the siblings of different age) it happened that the blind child didn't let the other one to push the button just at all.

At least one usability issue affected problems to the collaboration. The visual and the haptic feedback are not similar in the Space application. The visual interface on the screen is vertical as usually but the haptic interface is at a slope of 45 degrees. This caused problems when sighted child was guiding the blind one up or down. "Up" didn't mean the same direction for the blind child feeling the haptics as she/he should have moved the Phantom stylus slantwise up away, not vertically up. This came up in the first test and after that we paid more attention to the instructions and holding out the real world model of the menu in right angle of inclination.

6.4.2 Children's interviews

Generally the collaboration went right in children's opinion. They found it good that the sighted child was able to help the visually impaired to navigate. They noted that the sighted child can tell the other if she/he doesn't perceive something. The visually impaired child could feel where the stylus was moving while the sighted child could see it on the screen. One sighted child marked that the end of the stylus became smaller when it got towards the floor which helped him to follow where the other one was moving in the space.

One visually impaired child mentioned that it would be nice to have two Phantoms so that both of the children could hold their own stylus. When this was asked from the other pairs of children, one of them found it troublesome to navigate with two styluses: "...if one opens different door than the other..." They also wondered what would happen with the sounds if two persons were moving in different locations. The other children found it good or "maybe good" to use two sticks.

After the first test the children mentioned that it was hard to navigate up and down. That has also been observed from the video tape. The sighted child also said that it was difficult to instruct directions and the position of the stylus.

6.4.3 Parent's interviews

Two of the parents pointed out that the sighted children should have more active roles when using the application. Now those children were mainly acting as instructors or guides while the blind children followed their advices – or ignored them, which also happened some times. One parent suggested that there could be some activities where the visually impaired child could have a role of adviser. That was explained as it is not convenient that the blind people are so often those who need help and guiding.

One of the parents said that here should be more visual material for the sighted children in the application. Some of them thought that there could be more content or material on the whole. It was also proposed that there could be some game characteristics in the application, which might involve more collaboration between children.

Some of the parents thought that it would be better to have two Phantom styluses so that both children could be active and use the application better together.

6.5 Recommendations

The results of the tests will be analysed further in order to inform the further development of the application but also to guide the software architecture development. The following recommendations were derived from our analysis of the observations.

1. The visual and the haptic feedback should be commensurate in an application so that the children are able to discuss it. When the sighted child uses visual and aural feedback and the visually impaired child haptic and aural one it is difficult to get a common sense about navigation if the interfaces for different senses are not similar.

2. The visual feedback about the location of the Phantom stylus should be very clear. Otherwise it is difficult for the sighted child to know where the other one is moving on the virtual space.

3. It could be more convenient if every user had an own device to handle, but the application should be implemented so that the devices (e.g. Phantoms) work together and don't hinder each other. In applications like our Space application the implementation could be done for example so that the Phantoms lead by turns, one by one. When one Phantom acts as a leader the other one follows it and both children could thus feel the same things.

7 Audio and Haptic Feedback, Experimental Study

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7.1 Introduction

The experiment study presented in this article is based on a prototype developed 2006. The prototype has a visual and haptic interface and supports learning of spatial geometry presented in section 2 in this deliverable. In the prototype you can pick up and move around different geometrical objects, built composed objects out of smaller and so on. The prototype and the evaluation study performed with it are described more thoroughly in Sallnäs, Moll and Severinson Eklundh, 2007). Results from the evaluation show that it was problematic to acquire and maintain awareness in this kind of dynamic environment where things can be moved around by both users.

Based on the results of the evaluation in Sallnäs, Moll and Severinson Eklundh, 2007) we refined the prototype by, among other things, adding audio cues to increase the level of awareness. By doing this we want to see if audio cues make a positive difference when it comes to maintenance of awareness and common ground and the feeling of social presence. In this article only the qualitative analyses of the experiment will be presented.

7.2 Theoretical background

Awareness

The main benefit of working co-located compared to working distributed is that all group members have a good awareness of the presence of others, their activities, use of resources, knowledge, expectations and current goals (Neale et al, 2004). Dourish and Bellotti (1992) has defined awareness as “an understanding of the activities of others, which provides a context for your own activity”. Sometimes the mental states of other’s are also identified as awareness information. Since many terms has been used for different awareness aspects like situation awareness, presence awareness and social awareness, Naele et al. (2004) introduced the term activity awareness which encompasses all of the these.

When collaborating in groups the level of awareness of one’s own activities is crucial (Gaver et al., 1991). Verbal communication and perception of common objects, like physical artefacts, are two aspects that are essential in order to coordinate joint activities for groups and individuals that cooperate (Malone and Crowston, 1990). According to Kraut et al (1993) lack of this type of information decreases the quality in joint projects.

When sight is not available, as in the situation with collaboration among visually impaired and sighted pupils in school, awareness information cannot be transmitted through the visual modality. This often limits the visually impaired part’s possibility to obtain awareness. Several attempts have been made to get around this problem by e.g. using Braille displays and screen readers. The problem is, however, that the sighted and visually impaired pupils often have access to different work materials and different information and it is not always easy to translate between the different representations.

Common ground

Naele et al (2004) defines common ground as the joint awareness two people share. However, except from joint or shared awareness the shared context, culture and paradigms are also prerequisites for common ground. Naele et al (2004) also argue that if the proper levels of communication and coordination are supported, groups achieve common ground and acquire activity awareness critical for effective group functioning.

People use a kind of mechanisms to establish and maintain a common ground called grounding strategies (McCarthy et al, 1991). The dialogue between collaborators is the most important means of establishing common ground. Since the use of gestures also has been identified as important in grounding (Kirk et al, 2007), visually impaired people has a clear disadvantage here. For collaborating pairs including visually impaired people support for the dialogue is of utmost importance when developing applications with these users in mind.

References to objects like, “this one”, “the blue block” and “that wall” is called deixis and have also shown to be a great aid in the grounding process. With references like these you direct your partners attention to a specific object which both are aware of. Deixis have also shown to make maintenance of common ground much easier (Burke and Murphy, 2007).

Social presence and the haptic modality

Social presence is defined as “the salience of the other in a mediated communication and the consequent salience of their interpersonal interactions” (Short et al, 1976). Social presence is about how well a certain medium can transmit social information about the users involved, i.e. a subjective quality of a medium. The ability of a medium to transmit this kind of information influences the outcome of socially complex tasks such as negotiations to a large extent. Haptic perception is a combination of tactile perception (through the skin) and kinesthetic perception (the position and movement of joints and limbs) (Loomis & Lederman, 1986). There are different kinds of haptic feedback devices in use today, i.e. the 3 DOF PHANTOM devices, which can apply different kinds of forces to the user depending on the situation. It has been shown in many studies recently that haptic feedback increases the perceived social presence as well as the performance when groups of two users solving simple tasks together (Oakley et al., 2001; Sallnäs et al., 2004; Sallnäs, Moll and Severinson Eklundh, 2007). A few studies that were performed in MICOLE have shown that haptic feedback can make collaboration between a sighted and a visually impaired person possible in a graphical user interface (Sallnäs et al. 2006; McGookin and Brewster, 2007).

Audio feedback to visually impaired computer users

Not many studies have been conducted which involves investigation of audio feedback in interfaces for collaboration among sighted and visually impaired computer users. Winberg and Hellström (2001) have developed an interface based solely on audio feedback. They have invented a sound model that makes it possible for blind users to play the very popular game Towers of Hanoi. They use either three or four disks and each disk has there unique sound differing in pitch and timbre. The height of a particular disk is represented by the length of the sound and stereo panning is used to convey information about which peg a particular disk is on.

In (Winberg & Bowers, 2004) the above application was tested with three groups of users each containing one sighted and one blind adult. The sighted used a visual interface and the blind the auditory interface described above. They had to take turn in moving the disks and they did not have access to each other's representations. Since all pairs managed to solve the game this shows that it is possible to collaborate even though one of the users only had access to a sound interface. The potential of the support for the audio modality in interfaces for visually impaired users was in this way made clear.

7.3 Method

The main aim of this study was to test the hypothesis that supporting hearing as well as touch will improve collaborative task performance compared to supporting only touch.

Hypothesis

(H1) Haptic force-feedback improves task performance.

Participants

A total of 32 participants took part in our experiment. All the participants were adults and studying at KTH Campus in Stockholm. The participants were divided in pairs of two, each consisting of one blindfolded and one sighted person. We randomly choose who was going to be blindfolded. To make sure collaboration was encouraged every one who wanted to be a part of the experiment got to choose a person they knew, whom they wanted to work with. Thus, we recruited 16 of the participants who were all studying at KTH. Our only demand on the rest of the participants was that they should be in the age span 25-35, like most students are.

Software and hardware

The original Geometry Application

In 2005 a prototype for collaborative learning in small groups of children was developed and evaluated as a part of a master thesis [x]. Improvements have been made to this three-dimensional prototype, based on the results from the evaluation.

The prototype, called the Geometry application, is a three-dimensional virtual environment that supports collaborative learning of spatial geometry (geometrical shapes such as cube and cone, the concept of volume). The scene is a room where you look down through a totally transparent ceiling. The roof, walls and floor all have different and discriminable textures applied to them.

The tasks could be everything from feeling and recognizing the shape of a cylinder to building a larger cube by composing smaller cubes. The tasks are constructed and saved in a different application not considered here. In Figure 21, for example, a task in which you need ten cubes has been loaded.

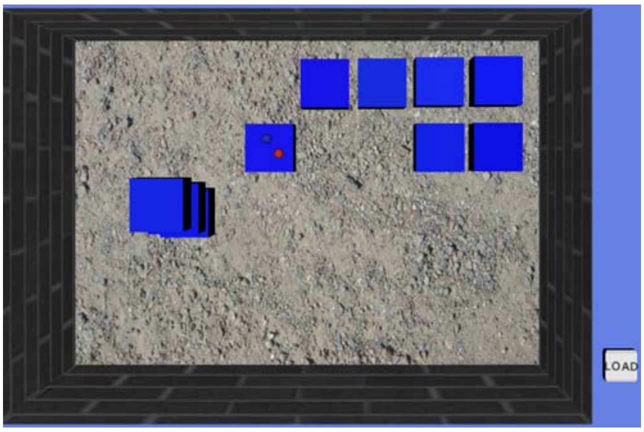

Figure 21. An example assignment with ten cubes. Both users are seen carrying the same cubes, three of the cubes have also been used to build a small tower.

Apart from feeling and recognizing the different geometrical shapes a user can also pick up and move around the objects by means of the phantom (in figure 18 two users are lifting the same object). In this way the users can co-operate in building larger shapes. Since gravity is applied to all the objects the pupils feel the weight and inertia as they carry around things. Users can also feel and grasp each other's graphical representations to provide navigational guidance e.g. to a visually impaired fellow. The users can also "feel each other" by means of a small repelling force, applied whenever the users' graphical representations touch each other. Since audio was not included in this prototype from the beginning the visually impaired user had to rely heavily on oral guidance from their sighted fellow.

Geometry Application with audio feedback

The only thing that differs from the original Geometry application just described is that this prototype has audio functions added to it. The visual and haptic interfaces are exactly the same. The following types of sound are used in this prototype:

- A "grip sound" is heard every time you lift an object
- A kind of "touch down sound" is heard every time an object touches the floor
- A "collision sound" is heard every time an object lands on top of another object

- A “contact sound” is heard every time you push down the button on the phantom. This “contact sound”, in stereo, is heard from one’s own avatar and it makes it possible for the blindfolded participant to locate the other user’s position relative to their own position.

Apparatus

The following hardware and software were used in the experiment:

- One personal computer with two dual core processors
- One computer screen
- Two phantoms (one Omni and one Desktop)
- Mouse and keyboard
- Reachin API 4.1 software
- Microsoft Visual Studio 2003 .NET software
- CamStudio for screen capturing

Procedure and Tasks

The experiment, which had a between group design, was divided into three parts with one training session, one group work session and one questionnaire/interview session. First of all, the researcher gave introductory information about the aim of the experiment, followed by an instruction on how to use the haptic devices. The participants then practiced in a training task how to feel the shape of a cube, how to navigate in the three-dimensional environment and how to grab a cube, lift it and hand it off to the other person in the group. Our sound groups were also introduced to the different kinds of sound. We made sure the participants felt comfortable with the blindfold and got used to working in this kind of haptic environment before the real tasks were loaded.

After the training session, which lasted about 15 minutes, the participants solved the following two tasks collaboratively:

- “In this assignment eight cubes of size 2x2 cm2 are placed on the floor, four at the bottom left and four at the upper right side of the room respectively. In the middle of the room there is also a large board with a size of 12x6 cm2. Your assignment is to build a table. The task has been solved when the board has been positioned 4 cm above floor level. The table legs should be at the respective corners of the table so as to give a good-looking impression. Before you start to solve this task you have to decide who is responsible for which group of cubes, you only have the right to touch your own cubes.” Figure 22 shows a screen shot of this assignment.

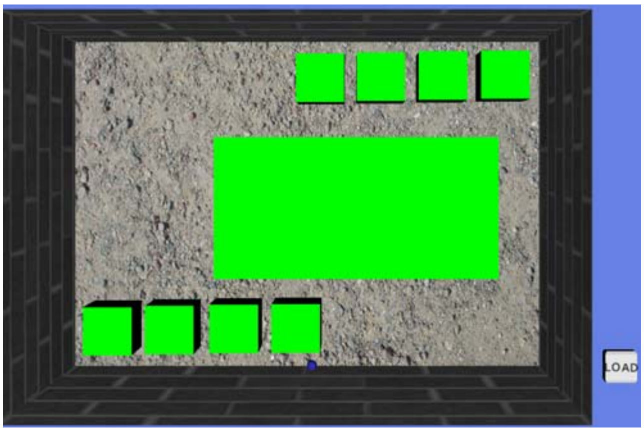

Figure. 22 The table building assignment directly after startup

• “On the floor there is now 7 building blocks of different sizes. 3 of these are cubes with volume 8 cm3 and the other types of objects have volumes of 8 cm3 or 12 cm3. None of the objects can be turned. Your assignment is to build a cube with volume 64 cm3 by using all of the building blocks.” Figure 22 shows the assignment right after it has been loaded.

These two tasks were solved in the program version the participants in a particular group had been assigned in advance. Thus, 8 out of 16 groups performed the tasks in the version including sound described above. The blindfolded participant used a PHANTOM Desktop and the sighted one used a PHANTOM Omni.

When the participants had completed their tasks they filled in a questionnaire where they graded their experience of the program and the collaboration. Since we did not use the questionnaire data in our qualitative analyses it will not be described further in this article. After the questionnaire had been handed in the participants were interviewed.

Interview

We conducted an open form of interview. The interview items aimed at exploring the participants’ thoughts about usability aspects regarding haptic and audio feedback. Among other things we wanted to know what kind of sound cues the participants in the haptic only group would like and if the participants in the audio groups could make use for the audio cues implemented. Questions about social presence, common ground and awareness aspects were also asked to give us more insight in how audio might affect these parameters.

7.4 Quantitative Results

The analysis of the data using ANOVA showed a significant results regarding task performance for task number one but not for task number two. Due to big problems with a bug in the program the data from one group could not be used and thus one group in the other condition was also excluded from the quantitative analysis.

Task Performance

The hypothesis for this experiment was concerned with the extent to which audio and haptic force-feedback improved task performance compared to only supporting haptic feedback. The results showed that task performance of the first task defined as total task completion time differs significantly ($p < 0.05$) across the two conditions. The mean task completion time was shortest for the three-dimensional visual/audio/haptic condition (M=581 seconds, s=284) and longest for the three-dimensional visual/haptic only condition (M=916 seconds, s=276), (Table 1). This means that subjects used about 10 minutes to perform the task in the visual/audio/haptic condition and subjects used about 15 minutes in the condition with no audio feedback.

There was no significant difference between the two conditions regarding time to complete the second task (Table 1). The reason is most certainly that the second task was very hard to solve and that most of the time was spent on discussions and not on manipulation of the objects in the virtual environment.

Table 1. Experimental results regarding total time to complete tasks for 14 groups.

			Haptic feedback	Audio + Haptic feedback
Task performance				
Task 1. (sec.) (n=14)	F=5.0	p=0.045*	M=581	M=916
Task 2. (sec.) (n=14)	F=0.006	p=0.94	M=1195	M=1173

*= significant at 95% level

7.5 Qualitative Results

Analyses

The video recorded group work sessions were analyzed and annotations were made for each session. The video analyses software, Transana, was used for the analyses. This software makes it possible to watch the video in one window and make annotations in another in real time. The observation technique was explorative in that we were open minded about which categories to use. Thus, the observation of the video recordings was not guided by any predefined categories. The categories identified as interesting during the analyses were: usability, common ground, awareness, guidance, social presence and modality. The video recordings of the interaction in the shared virtual environment, including the communication between the participants, were analyzed. Annotations were made for each evaluation session describing the users’ interaction with the interface and with each other for each group respectively. Both the behavior and the verbal communication were annotated. Interpretations of interesting parts in the interaction were also annotated where needed. Afterwards each peace of data was categorized (peace of data could be dialogues, utterances or description of events). This was done by going through the transcripts in Transana, putting the respective category name in bold face before each data peace. The data, which were first sorted by time, were then sorted into the different categories as a way to ease comparison between the different categories for the different groups and experiment conditions. Each data peace was then divided into findings that were unique for audio groups, unique for haptic only groups or general. The data from the different categories were then compared in order to derive general as well as unique findings. In a last iteration we extracted particular dialogue examples as a way to illustrate findings.

The interviews were transcribed in their entirety in Transana but neither expressions of emotion nor pauses were transcribed. Annotations of interpretations were made for each meaningful unit of the data material and a number of categories were defined. The data was analyzed in this way for each group. Finally, all pairs were compared in order to obtain general findings and interesting patterns in the results as well as unique but yet informative findings.

Results and conclusions from observations

In this section we will present and elaborate on the important findings derived from the qualitative analyses of the experiment. We will not only focus on differences between the two conditions visual/haptic/audio and visual/haptic respectively but also on other interesting findings search as ways of giving guidance and grounding tactics.

Usability

Generally, across both experiment conditions, the blindfolded had no problem in using the haptic equipment. Evidently it was also easy to feel things and to distinguish between objects, textures and heights. The sighted participants had a harder time using their equipment, much due to the PHANTOM Omni having much lower resolution and update frequency than the PHANTOM Desktop, used by the blindfolded participants. The sighted participants often got their avatars stuck inside of objects and they had a harder time feeling details. Bugs like getting stuck inside of objects were equally frequent in both experiment conditions but they nonetheless influenced the work flow in a bad way. However the difference between the equipments gave the blindfolded participant an interesting advantage – he/she could feel details like height differences much easier. Example 1 below, illustrates a typical situation, taken from an audio group. The blindfolded participant is currently on one of the cubes.

Example 1. The blindfolded’s advantage in the cooperation

Sighted:	Can you feel how big they are?
	[Blindfolded moves around the cube for a while]
Blindfolded:	These might be 2x2x2
Sighted:	Yeah, I guess so.. but it seems we have five of these 2x2x2 actually, but they are in two different colors, green and blue, so there has to be some difference between them
	[Sighted feels on both the cube and a tall block, but is not successful]
Blindfolded:	The blue blocks, where are they?

[Blindfolded guided to one of the tall blocks and moves up and down on it for a while]

Sighted: What is the difference?

Blindfolded: The height is more on this one

Sighted: It’s high?

Blindfolded: Yeah it’s longer

Sighted: Ok, it's higher.. then the blue one should be the 2x2x3.. So what we have is like two of the 2x2x3 and three of the volume of 8, so they are cubic which means 2x2x2 and ... did you get to feel any of the bigger ones?

[They now move on discussing the long blocks and their orientations]

In our setting, described earlier the sighted was watching an ordinary, upstanding, computer screen. This means that the sighted saw the blindfolded’s avatar moving up and down on the screen as the blindfolded moved backward and forward on the floor level. Thus they had different perspectives, the sighted participant saw the floor in front of him while the blindfolded felt the floor when she pushed from above. This issue caused some trouble when it came to establishment of common ground, something we will elaborate on later. The perspective had one positive influence, though, the sighted was forced to use the haptics to feel heights, since he/she could not see them from the given angle. Although example 1 illustrates the most typical situation, the perspective showed us that haptics can be beneficial for sighted computer users as well.

The functions we referred to above as the haptical guiding functions were used in most groups, some used them more than others. It was easy and fruitful for most groups to hold on to the same cube, the grasp function was harder to use though due to high forces. When it worked, however, it was shown to be a great aid.

The audio feedback

Generally all participants in our audio groups used at least some of the audio cues to communicate with each other or acquire awareness of changes. We can conclude from the observations that they were easily understood and that they could be used in the intended way. We will describe how they used these audio cues in later section.

Although the sound was 3D we noticed that it was hard to hear front/back and up/down. For example, when they used the contact sound the blindfolded could position her/himself correct in the left/right direction but additional verbal feedback was needed to guide in the other directions.

Another sound problem was that the collisions sound was heard even though the particular object was not dropped, it was enough to just touch another surface. If you touch a surface and then slide the object on that surface collision sound is not heard on release. Questions like “Did I drop it?” or “Have you dropped it?” arose from time to time due to this.

Common ground

When it came to grounding strategies and maintenance of common ground it did not seem to matter much whether there is sound present or not. Here we are going to elaborate on some general findings that were not affected by the experiment conditions.

Grounding strategies

The groups used different grounding strategies for establishing a common ground, not affected by the experiment condition. Almost every group started out, in both assignments, by going through every object discussing them. Example 1 above is a typical example. Example 2 is another example which deserves a closer look.
Example 2. The use of grounding strategies

Sighted:	I'm just trying to find out which blocks are the highest...
	[Sighted feels around and ends up on a high block]
Sighted:	… yes, the blue ones are highest
Blindfolded:	Ok
Sighted:	and the other one..
	[Blindfolded moves around and ends up on a long block]
Sighted:	there are two... you're at a red one now..
Blindfolded:	That one?
	[He points repeatedly to the long block to clarify]
	[He then moves along the long and short edges, respectively]
Blindfolded:	quite short.. quite long
Sighted:	Yes, and the height..
	[Blindfolded moves up on the box and down again a few times]
Blindfolded:	short!
Sighted:	Yes, the low ones... The other one is.. no, up in the corner
	[Blindfolded navigates to the forward right corner]
Sighted:	There it is
Blindfolded:	Ok
Sighted:	This is the other way..
Blindfolded:	Yes, turned 90 degrees left,.. ok

It is interesting to look at the way the haptics is used when grounding. As can be seen in the above example the blindfolded uses the haptics to point out the object he thinks they are talking about. He does this by touching the object repeatedly from above. The touch modality make it possible to establish common ground in a rather simple way. Without the haptics this grounding dialogue would probably have been longer. You can also see from the above example that the sighted talks about what the blindfolded feels – the haptics make it possible to focus on a particular object at hand, something that is very important when grounding. It is also clear, from the above example, that the haptics makes use of deixis possible. The sighted refers to “this” a number of times. This also says something about how the haptics influences the feeling of social presence. As the blindfolded feels on the objects the sighted describes them, like they were actually there together wondering around in the room. Last example two shows

how you can refer to boxes. This particular group referred to the objects by their color, but the most usual way was to use the dimensions like in example 1 above.
A few groups used a different, but yet interesting grounding strategy. The sighted participants arranged the different types of blocks in the second task so they were lying side by side. In this way the blindfolded could easily feel the height relations.
The most common way of maintaining common ground was to ask questions. The blindfolded often asked questions about what was currently felt or about what had been built. Sometimes the sighted also asked clarifying questions like “Do you feel the floor?” The participants often went back to discussions about the different dimensions and often the blindfolded was guided around what had been built, especially in the second task.

Amount of common ground in the different groups

Generally the participants in a group seemed to share a good amount of common ground, regardless if there is sound cues or not. The following dialogue should serve as a good example:

Example 3. Common ground

Blindfolded:	Can you try like,.. you have one that is 3 high, and then,.. well, one of these 4 long you have that one in the bottom and you put one that is 2 high on top of that and then…
	[Sighted places a cube (2-high) a tall block (4-long)]
Blindfolded:	…to the side of that you put the one that is…
Sighted:	3
Blindfolded:	"..3.. and then you put the one that is 4 on top of it
	[Sighted moves everything into place]
	[They then move on to form the final result]

Obviously the participants in this particular group shared a common ground about the different objects and how the different dimensions would add up. Actually, in this case, the blindfolded were the one solving the assignment. This was actually the case for almost half of the groups, something that says a lot about common ground. The participants were often highly engaged in discussions about dimension and how different blocks should go together. Again these discussion are mostly based on what the blindfolded feels for the moment.

There were also a few problems regarding common ground. The biggest obstacle to overcome was the perspective difference mentioned earlier – the participants experienced the room from two different angles. This often caused confusions when it came to direction words. For example they often confused “up” with “forward” in the beginning. The blindfolded moved towards the roof when the sighted wanted him/her to move up on the screen, towards the front wall in the room. For a few groups the colors were also confusing, in those cases they did never have a thorough discussion of colors and dimensions in the beginning of the second task.

Communication and guiding strategies

The participants in the audio groups could communicate in three ways, verbally, haptically and with audio. The other groups only had their speak and the haptics. Verbal communication was by far the most utilized form of communication, especially in the beginning of the tasks when the participants had to establish a common ground. The haptics was a good complement to the verbal communication as discussed earlier. Audio can also be used as a way to communicate, e.g. by using the contact sound to show where you are.

Verbal guidance

The following dialogue shows a very typical example of verbal guidance. Here the blindfolded participant is guided on how to place one of the long blocks in the resulting cube.

Example 4. Verbal guidance

Sighted:	Ok, right,.. right, right,.. left,.. feel, .. you can feel the corner
	[Blindfolded moves to the upper right corner]
Sighted:	... and then go to the left a bit.. stop!.. down.. left, left,.. down,.. go down till you feel the ground.. and then go forward until you feel the wall…
	[Blindfolded moves the block to the upper wall, sliding it on the floor]
Sighted:	... and right until you feel the boxes,... so, yeah,... let go

As can be seen in example 4 verbal guidance works, but it can be pretty cumbersome. In this group they used the direction words right, left, up and down (up and down meaning forward and backward in the room respectively). Other groups used points of the compass and some used forward/backward instead of up/down. The important thing here is that every group managed to establish a common ground regarding direction words.

As can also be seen in the above example they often use interface elements like “the floor”, “the wall”, “the corner” and so on. This way of giving guidance was also used in most of the groups and of course referring to interface elements makes it a whole lot easier. It is not hard to see that this would not work without the haptics, you can not use the interface elements like this if you can not feel them.

Haptic guidance

We had two types of haptical guiding functions witch were introduced to the participants in the training task. You could either hold on to the same cube or grasp the other person’s avatar. The first of these two functions was the one most widely used. In almost every group they placed the board together to conclude the first assignment. This was not necessary, of course, but it made the blindfolded participant more involved. In the second assignment they placed at least some blocks together in most of the groups. In this way the blindfolded could be involved in the work process in an easy way. As we saw in example 4 verbal guidance could be very cumbersome. If there were no way of guiding or communicating haptically the process of doing things together would be much harder. The risk is that the sighted would do everything on his own in that case.

The second function, grasping the other's avatar, was used by only a few groups. This was much due to this function being unstable. However, example 5 below shows the true potential in this kind of guiding function. The sighted participant has just built an L-shape with the two long blocks and placed some other blocks close to the L-shape.

Example 5. Grasping the other's avatar

	[Sighted grabs the blindfolded's avatar]
	[He drags the blindfolded to the beginning of the L-shape]
Sighted:	Now, here we have an L-shape..
	[Sighted drags the blindfolded to the top of the shape]
Sighted:	… this is the top.
	[Sighted now drags the blindfolded back and forth on the L-shape's north-southern part a few times]
	[He then drags the blindfolded to the east, until the shape ends]
Sighted:	Ok, and this is the bottom right... and then we have this cube that is taller than the others
	[He drags blindfolded up and down on a tall block placed beside the L]
Sighted:	We have another one just like it

As this example illustrates that you can actually show things in a very physical way, by grabbing the other person. This is a way of communicating haptically which conveys a lot of information which does not need to be spelled out. This way of communicating or guiding also adds to the feeling of social presence when using the interface. This also shows the true potential of haptics in interfaces for visually impaired users.

Apart from using the methods described above some groups invented there own methods of using the haptics for guiding purposes. For example, in one of the groups the sighted pushed the blindfolded's cube with one of his own in the first assignment. This was a way of giving guidance without actually touching the blindfolded's cube (this was not allowed). In another group the sighted participant held her avatar in the way to create a physical stop, so that the blindfolded's table legs should end up at appropriate places. Again these examples show how you can use the haptics to communicate information in these kinds of interfaces.

The benefit of haptics – an illustrating example

To conclude this section we will show another illustrating dialogue, example 6, where the blindfolded actually solves the second task. Note the use of the haptics, especially when the blindfolded moves over a big part of the room pointing at a specific object. The example also shows that the participants share a good amount of common ground.

Example 6. The benefit of haptics

Sighted:	Everything that is 3 high has to be combined with 1
Blindfolded:	Yeah
Sighted:	And there are two of them right now [Blindfolded moves up to the front right corner]
Blindfolded:	One in the corner here
Sighted:	Yes
Blindfolded:	And the other one should be here [Blindfolded moves around on the floor in the backward left corner of the soon-to-be cube]
Sighted:	No
Blindfolded:	Closer to me.. so that this one can be on top.. [Blindfolded points to a long block more than 1 dm below!] [Blindfolded then moves with his avatar back and forth on the left side of the soon-to-be cube to show what he meant with “on top”]
Sighted:	But we have only two of those that are 3 high
Blindfolded:	Yeah
Sighted:	...but we have two of the flat ones
Blindfolded:	Yes.. I think I have a pretty good picture of how it should be
Sighted:	Ok, so where do you want to put it? There is something wrong now, one is standing on the floor and the other one on the long one [Sighted refers to the 3-high (tall blocks)] [Blindfolded points to the one standing on the ground]
Blindfolded:	I want to put it closer to me.. It should be close to me and next to the lying one in the corner
Sighted:	Next to the lying one?.. What you currently have is one flat one lying in the corner
Blindfolded:	Yes, and on top of that there should be one three high and one two high [That is the current situation]
Sighted:	Yes
Blindfolded:	And then, going towards me from the 2 high you should have a 3 high standing on the ground [Now, the sighted sees the solution and the remaining blocks are placed]

Communicating with sound

The contact sound was used as a way to communicate regularly in at least half of our sound groups. Despite the fact that it did only work in the left/right direction it showed to be a great aid when guiding. One of the groups actually used it more than verbal guiding, the sighted participant in this group used verbal guiding as a complement or when the sound did not work (forward/backward direction). If we look at example 4 again a big part of that dialogue could probably be replaced by some instances of the contact sound. Example 7 below shows how the contact sound was used.

Example 7. Using the contact sound

Sighted:	Pick up a new cube
	[Blindfolded locates a cube on her own]
Blindfolded:	That one?
Sighted:	Yeah...And then you can move here...
	[Sighted uses sound to show the way]
	[Blindfolded navigates to a place slightly above the intended one]
Sighted:	Ok, down a bit..., down..., stop
	[Blindfolded releases]
Sighted:	You can try to pick up the cube that's here...
	[Sighted uses the contact sound again]
	[Blindfolded navigates to the exact place in a few seconds]

As can be seen in example 7 the contact sound conveys a lot of valuable information, information that otherwise had to be given verbally. We have also seen that the blindfolded participants were more often guided in the sound groups, probably because the sound cue decreases the work load on the person who has to guide. Thus, the way of giving guidance and the work load of giving guidance is affected positively by the addition of a sound cue. Example 7 also shows that the sound affects the dialogue in a subtle but yet interesting way.
It is also interesting to consider the use of deixis in the above example, like “come here”, “the cube that’s here”. The sound can also be used, with some limitations, to point in the interface and discuss different objects. The sighted can use the sound as a pointing device and the blindfolded his avatar. In this sense the sound is also positive when it comes to the feeling of social presence.

Awareness

When it comes to awareness aspects it is clear that audio cues make a difference in a positive direction. These kinds of cues tell if something is changing and make the blindfolded participant aware of that work is in progress. It is also clear, though, that the second assignment might have been a little too hard for persons not good at math. In almost one third of the groups the blindfolded participant had no idea of how the final result was constructed, regardless of whether there were sounds present or not. Thus, this very mathematical task may not be suited in this type of experiment – the affect of the cognitive work load probably clouds the affect of the sounds. However, if we look at example 6 again, we see that it is also very possible to obtain a good amount of awareness. Here the blindfolded knows where things are, the status of the work and what to do with the different building blocks.

The benefit of haptics

It is interesting to consider how the haptic modality affects the level of awareness. If the haptic modality was not supported it would be very hard to track changes and to do things together. Everything would have to be spelled out by the sighted. Probably the sighted would prefer to do everything by himself/herself and the blindfolded would be totally excluded.

One very clear advantage of haptics in this case can be studied in examples 2 and 6 given above. The blindfolded can point to and feel on objects as the sighted speaks about them and in this way they are both aware they are speaking about the same thing. Of course, for this to work, both have to be aware of that both avatars are visible. In example 6 we can also see how the blindfolded uses the avatar to make the sighted aware of what he is talking about. Every group, exclusively, made use of this way of maintaining awareness.

The haptics could also, to some extent give awareness of where the other person is. For example a few of the sighted participants made use of the small force generated when the avatars coincides. This was a way of telling the blindfolded they were both around the same object. The feeling when you are lifting the same object also conveys awareness information of that you are actually collaborating. Last, the sighted participant sometimes pushed at the opposite side of a block the blindfolded held to tell where he/she was or to guide in a certain direction. At the same time the haptics conveys information about the other person's whereabouts it also, of course, adds to the feeling of social presence.

The significance of audio feedback

The haptics can be used to track changes, while feeling around on the floor – you can feel if something has been moved or is showing up at a new place. You need to constantly explore the whole work space, something that was evident when studying the groups who did not have access to audio feedback. In the audio groups, however, the sounds instantly tell if something has been moved or placed down. You do not need to explore to know that something changed and you are always aware that work is in progress. Interestingly enough one of the blindfolded participants in a sound group felt a little anxious when she had not hard anything for a while, and asked her peer "So, what's happening now?". It had been quite for a while because the sighted was just looking at the table legs without moving anything. In the groups without audio questions like "Have we started?" and "Are you doing anything?" were frequent, telling that the blindfolded was not aware that work was in progress.

Another advantage of audio cues is that they give awareness of what you are doing yourself. It was clear from our observations that the feeling of lifting an object did not give enough information to the blindfolded participant. The same could be said about the dropping of a cube. In our haptic only groups questions like "Did I drop it?" and "Did I pick it up?" were frequent. Obviously the touch feedback was not enough confirmation. These kinds of questions were never asked in the audio groups. The sound was a confirmation that you did what you wanted to do. It would definitely be possible to do things without audio feedback, but the sense of comfort would probably be affected in a negative way. Example 8 below shows another advantage with the collision sound.

Example 8. Awareness information mediated through sound

	[Blindfolded accidentally drops the cube she is holding]
	[The collisions sound is heard]
Blindfolded:	Oh, I dropped it now
Sighted:	Yes, you can pick it again if you feel it
	[Blindfolded picks up the cube again]

In this example the sound made the blindfolded aware of that the cube had been accidentally dropped. She did not have to wait for the sighted to tell her this. In some of the haptic only groups, however, it could take quite a while for the sighted to realize that a cube actually did not move with the blindfolded's avatar. In another case the blindfolded dropped a cube several times in a row without noticing it. Each and every time he had to wait for the sighted to tell him the cube was dropped.
The difference between touch down sounds did also convey valuable information despite the fact that they were a little bit too close. Example 9 illustrates this, when the blindfolded is placing a cube on another to build a leg.

Example 9. The advantage of different touch down sound

	[Blindfolded puts the cube down, floor collision heard]
	[Blindfolded puts it down again, floor collision again]
	[Blindfolded lifts and places the cube on another, object collision heard]
Blindfolded:	Does it look nice?
Sighted:	No…
Blindfolded:	But I know it's on top…

In this case the sighted did never have to direct the blindfolded in order for her to be able to place the cube on another. The sound was enough. In the haptic only groups the sighted had to give verbal guidance while the blindfolded was moving up in the air, it is not hard to see that sound makes a big difference for the better in this case. The blindfolded participant could actually to some things completely by his/herself, he/she is not completely dependent on the sighted peer. Example 9 illustrates another advantage given by the audio modality.

Example 10. Audio feedback good for sighted users as well

	[Blindfolded is feeling around on a long block]
Sighted:	Ok, you can pick that one up again
	[Blindfolded continues feeling the object for about 10 seconds]
	[Blindfolded grasps the object, grasp sound is heard]
Sighted:	Ok
	[Sighted starts to guide to the correct place]

This example shows that the sounds gives the sighted participant awareness information as well. He tells the blindfolded to grasp the cube, he waits until he hears it has been grasped and then he starts to guide. Thus, the sound is also helpful for the sighted. In the haptic only groups the sighted participant had to ask questions like “Did you drop it?” or “Did you grasp it?” all the time. Since those kinds of questions never arose in the audio groups we can conclude that the sound is enough confirmation and that it gives valuable awareness information to both the blindfolded and the sighted participant. Thus the sound eases the collaboration, you can concentrate more on the task than the constant need to ask and in other ways find out what happens.

There is no question about that sound increases the level of awareness in our prototype. It does also increase the efficiency in the work process, giving information that otherwise had to be conveyed through verbal guidance and communication. It is not clear, though, how big this impact on efficiency is, we probably need to have more simple tasks to be ably to make conclusions about this. Of course there are problems with this sound model, it is hard to hear where things have happened and you can get collision sounds without actually dropping an object. At least the sound model gives the blindfolded participant a sense of what the other person is doing, that work is in progress and a confirmation of his/her own actions.

Results and conclusions from interviews

Usability

Generally the participant thought it was funny and interesting to work with the system. This was a new way of using the computer and “taking the mouse to the next dimension”. Most of the groups also liked the challenge of communicating when one of the co-workers has lost a vital sense. The most valuable function was, according to most of the participants, that you could actually feel something. Actually, when we asked about which type of feedback gave the most valuable information almost everyone answered the haptics. Haptic feedback was identified to be absolutely necessary for the blindfolded and a good complement for the sighted.

When it comes to the sound feedback we got mixed results. Most of the audio groups made use of the audio feedback and the participants understood how to use them. The grasp sound and contact sound were identified as most helpful, but yet problematic. It was especially hard for the blindfolded to hear where the sound came from. A few blindfolded participants also complained about there being too many sounds and that there were no difference between sounds from the two users. Some of the blindfolded subjects also had a hard time distinguishing between the two collision sounds. Here is an example dialogue from the interviews illustrating the sound feedback problem:

Sighted:	Well, the audio was kind of hard to use because it was hard to show,.. I’m here
Blindfolded:	Yeah, it was a little bit hard to tell, actually
Sighted:	…but it helped sometimes to get her to a location
Blindfolded:	Yes, sometimes it worked but,.. I kind of thought it was hard to tell the difference if you dropped it on another object or if you dropped it on the floor. It sounded a bit different but I could never quite,.. I always

> kept wondering like, wait was that on top of something? Only if you told me I could actually..

Most of the sighted participants found it very frustrating to get stuck inside of objects. Most of the groups also found it hard to work with different perspectives, they often confused the direction terms in the beginning. One blindfolded participant said the following:

The thing with these words,.. because you wanted to say "up" and I wanted to say "in front" because the thing I see is this flat thing here in front of me and she sees it upside down on the screen. But I didn't know you saw that so I didn't know why you wanted do say "up".. I didn't think about that until now,.. cause I never saw the screen and I didn't know that..

The haptics was found easy to use for the blindfolded participants, they could easily discriminate between objects and textures. Some of the sighted participants had a harder time feeling details, though. This is due to the lower resolution of the PHANTOM Omni.

When we asked the participants about ideas for improvement they came up with different kinds of sound cue refinements in the audio groups. In the haptic groups, however, almost everyone said they wanted sound cues like a contact sound and sounds for colliding surfaces. This is quite interesting since that is just the type of cues we have implemented.

Common ground and social presence

The participants in almost every group felt they were working in the same environment together. Most of the group got this feeling because the blindfolded could point to and feel on objects while the sighted talked about them. The blindfolded also noted the sighted person’s changes in the environment and they could feel each other’s proxys when they were close.

In most of the groups the participants did not believe they had the same view of the environment. This was often explained by them having different perspectives. In most groups, however, the layout of the room and the objects in it were seen as common view. This view was often built up by the blindfolded when he/she was feeling around on objects while the sighted described them. Thus, the haptics was very important when the participants needed to establish a common ground.

When it came to the tasks the vast majority of the groups had a common view about the first one. It was seen as pretty simple and they could imagine in their minds what the result should look like. In the second task it was harder, though. Especially the blindfolded participants did not believe they had the same view of how to go through with it. The second task was seen as very complex and it was hard to plan in advance. Some groups highlighted the importance of having a common ground about direction terms. They also found these common terms to be a basis for the collaboration. Some groups also talked about the importance of having the same object references:

Sighted:	Yeah, I had to use some way to, instead of using the dimensions of the boxes which was quite hard to explain I used colors just to assign a color with a dimension
Blindfolded:	Yeah, I remember you told me "this is the red one" and I could feel it first and I remember the shape

Awareness

In the majority of the groups the blindfolded participant did not know that much about what the sighted person was doing. In the sound groups the blindfolded participants could hear that their co-worker was doing something, but they did not have a very good sense of what was done and which object was moved. One respondent said:

Even though I could hear that she was somewhere to the right or to the left of me it doesn't help because,.. probably because I'm not blind, this feel for me wasn't really clear where all the cubes were and where everything was so it's not like I had this perfect image. If she is picking something up "Oh, she's probably lifting the cube in the right corner", I couldn't figure that thing out from my picture, so I was concentrated on what I was doing instead of trying to figure out what she was doing.

In the haptic only groups, the only way to track the other person’s actions was to be at the same place or holding the same block. Most of the participants said that they tracked the other person’s actions primarily by talking and not so much by using the feedback. Some of the respondents did not feel the need to know what the other person was doing.

Most of the blindfolded participants also reported that they found it hard to track changes in the environment. Once again the blindfolded participants in the sound groups knew something was changing but not what and where. In the haptic only groups the only way to track changes was to constantly move around feeling what has been moved. One blindfolded participant complained about that she constantly lost her orientation when objects disappeared and ended up at different places:

The first time when you go and feel the cubes and so on it's good but when the other one goes and replace it somewhere else its way hard to find or know where it's placed or where should I look? So you loose your coordination in the room where you are, so you must go and seek, "where is the back wall and the corners?”

Even though the level of awareness of changes and of the other’s actions was pretty low the sound was identified to be an aid in several cases. In the haptic only groups the majority of the blindfolded participants believed that sound cues would help them to keep track of the other person’s doings. Something that was also evident from the observation analyses. One sighted participant from an audio group reported that the sound helped him to track the blindfolded’s actions – he did not have to look at what he was doing all the time. We will conclude this section with some very informative words, coming from

With no feedback it wouldn't be possible but without sound I think it would be possible but it wouldn't be as easy, and it would be kind of boring for me because I had no idea of what he was doing if I hadn't have the sounds

7.6 Discussion

In this article we have described and elaborated on the results of an experimental study comparing a visual/haptic interface with a visual/haptic/audio interface. The results clearly show that the added audio functions make a difference.

In the earlier study Moll & Sallnäs (2007) one of the biggest problems was the lack of awareness the visually impaired user gained in the work process. This was much due to the fact that objects could be moved around by all of the users present, thus the visually impaired user does not have total control. In our haptic only groups we noticed the same problem, both of the users often had to ask what was going on and seemed like the blindfolded participants in these groups were more unaware of what was going on. In collaboration settings this is, of course, a major problem. In our sound groups, however, the results were more encouraging. They could use the sounds to communicate information and even though the 3D-model could be greatly improved the sounds were obviously helpful when it came to acquiring awareness of what went on. Even though the blindfolded participants in these groups were not doing things all the time the sounds gave them comfort in knowing that work was in progress and that the system was running. Thus, one should be able to conclude that the presence of sound makes a considerable difference when it comes to awareness.

It has to be pointed out, however, that the sound model used is rather simple and that it sure has its limitations. It was sometimes really hard for the blindfolded participant to hear where the contact sound came from, something that is rather problematic since this sound is used for locating the sighted user. However, we could also see the potential of this kind of sound. It was especially hard to know if a sound came from the front or the back. But then again we could clearly see that this type of sound was useful. If we improve the sound model and add ear-phones we are convinced that the results would be even clearer, at the benefit of the audio feedback.

We also concluded that audio feedback did not have that much impact on the amount of common ground acquired. This is much due to the fact that common ground is established mainly through dialogues. We did show, however, that the sound had an impact on the dialogue. In the haptic only groups much time was devoted to asking clarifying questions like “did I drop it now?”. In our audio groups these types of questions never arose. Thus, the sound affected the dialogue in a positive way and made it possible to concentrate on the actual task.

The haptics also had an important impact on the dialogue – the fact that one could feel the objects made it possible to discuss them more directly. The sighted participant could talk about what the blindfolded felt for the moment and adapt his way of talking to the blindfolded’s haptic model. The participants also used numerous deictical references which made the collaboration easier and allowed them to focus more on the task. Even though we could not see that the sound made a difference regarding common ground the results clearly show the potential of haptics in that area.

When it comes to social presence our results correspond well with earlier research (like in Oakley et al., 2001 and Sallnäs, 2004). The haptics did have a positive impact on the feeling of social presence. They discuss common objects as they were together in that particular room. The fact that you can feel each other and each other's forces on shared objects also gives an impression that the other person is actually there. One can imagine that this feeling of being socially co-located is even more important when you cannot see. The haptics makes it possible to interact in a way that would otherwise be impossible. We could not see big difference regarding social presence between the two experiment conditions. This is probably due to the fact that the sounds are quite artificial and you do not feel that you are co-located with the avatar (you are not surrounded by sounds, like you were actually in the room). This highlights an important aspect of virtual environments – the level of immersion. If the participant were ear-phones they would be more immersed in the virtual environment and they would probably think of the sounds as coming from each other rather than from the computer. It would be interesting to conduct new studies with a greater amount of immersion to see if this changes the role of the audio feedback.

8. Meta Analysis of the Field Study Performed Year One

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8.1 Introduction

A field study was conducted in five different countries from the participants of the Micole project (Austria, Finland, France, Scotland and Sweden). This investigation was performed in order to study how visually impaired children collaborate in school with peers and teachers and to what extent the visually impaired children are engaging in group work in different countries.

8.2 Research questions

Visually impaired children are often disadvantaged in a group of sighted peers and easily fail to contribute satisfactorily just because the information shared by the group is most often inaccessible.

Collaboration may take many different forms. In this study we focus on school work, then we consider especially co-located collaboration: collaboration takes place in the same location at the same time. Co-located collaborators discuss and manipulate artefacts and information items in a shared context. In the last 2 decades we could observe a growing importance of Information Technologies. The main difficulty of collaborative tasks for visually impaired people is the access to these artefacts and information items. The use of Information Technologies should allow a real improvement of this situation if they are accessible.

There are a number of interesting problems that have to be addressed concerning collaboration between sighted and blind people. The main problems have been identified as follows.

First, blind people do not get access to all relevant information. Obviously this applies especially to graphical information (maps, drawings, maths curves etc.), but also in most situations to textual information which for many reasons (it's often a question of time) were not transcribed into Braille. Notes taken by the collaborators whether on paper or on any kind of blackboard are also not accessible. Even if a computer and beamer are used (it would be technologically possible to make it accessible but most of the time the various technologies present locally are simply not compatible). If videos are used, they are mainly inaccessible too. Additionally to this, even when accessible documents are available, blind collaborators have hardly access to overview of the information available. Usually in a classroom situation the work documents are available in Braille but the problem of graphics, blackboard and peers notes is still present.

Secondly most sighted people cannot read Braille. If the Blind collaborator is using paper then in most cases the others will have no access to it. If the Blind collaborator is using a computer with Braille output then the text can be displayed on a screen but there are still difficulties of localisation: sighted have no idea what part of the screen is displayed on the Braille, which can possibly not be actually on the screen at this time (in a scrolled window). Reversely they can hardly show to their Blind peer a specific part of the text. This situation is made worse if the Blind collaborator is using a speech synthesis, which can be disturbing for the others etc.

To conclude in most situations the visually impaired pupil in a classroom has only language as a means of collaboration with sighted peers or teachers. The aspects of collaboration in which they are disadvantaged can be summarized as follows:

- access to information (non-textual information, lack of overview, videos, maps, maths, blackboard...)
- share of their own work
- engaging in non-textual creation

The following research questions are aimed to find solutions to the most important problems, in order to improve collaborative work between sighted and blind people:

- How can we integrate accessible and graphical view in the same tool so that everybody can read, produce, and share the same information?
- How can we use multimodal representations (Braille, haptics and audio) to allow blind collaborators to have access to graphical information?
- How can we realize a tool that combines the various forms of writing (black, Braille) and the various functionalities which allow the blind people to have access to the graphical information and allows them to be independent and mobile?

8.3 Methodology used in the field study

To study these questions five of the MICOLE partners conducted a field study in their country in order to explore situations involving collaboration among visually impaired and sighted pupils at school, as well in learning situation as playing with friends. The aims of the study were:

1. To investigate specific issues of collaboration in cross-modal interfaces in order to gain a better understanding of how visually impaired and sighted children can interact and learn on equal grounds.

2. To make a mapping of problems in interaction between sighted and visually impaired children in collaborative situations in their environment in the field.

The field study was based on interviews and observation *in situ*. First we have to stress the fact that the educational situation of impaired children, and especially visually impaired children, is very different in the various European countries. The five countries in which this study was conducted include the different situations found in Europe (from complete inclusion to complete segregation). The study was conducted by Johannes Kepler Universität Linz (ULINZ) in Austria, by University of Tampere (UTA) in Finland, by Université Pierre et Marie Curie (UPMC) in France, by University of Glasgow in Scotland and by Kungliga Tekniska Högskolan (KTH) in Sweden.

Visually impaired children have been interviewed in their schools, whether it was special schools or mainstream schools (in an inclusive education system). In each case their teachers were interviewed too. In the case of mainstream schools, sighted peers were also interviewed.

The interviews covered issues concerning collaboration between the children during school work, different kinds of group work, their information handling in school, their communication with other children and the teacher and finally some questions about games and play.

For the study, interview guides for the interviews with teachers and children were developed as well as an observation guide and a consent form. The partners made local modifications to these guides so that they were relevant in each country, and to their own research domain. For instance University of Linz and University Pierre et Marie Curie focused more on Mathematics. Additional question aiming at a specific population could also be added (e.g. in Scotland: the MICOLE project is aimed towards providing accessible interfaces for children and the majority of participants were older than the target age group, participants were asked to think back to their interests in childhood as well as talking about their current interests and hobbies).

8.4 Results of the meta-analysis

First we summarize the results from the five field studies. The dimensions used for the meta-analysis are the different educational systems observed for visually impaired pupils, the special equipment available for visually impaired pupils, the group work difficulties and to conclude the visually impaired children's feeling about group work.

8.4.1 The different educational system for visually impaired pupils

The situation is very different in European countries even if we can observe a global small evolution towards inclusive education. In the 5 countries where the study was conducted, all different situations where represented.

a. Both mainstream and segregative education cohabit

The more common situation is the situation where families have a choice between mainstream or special school (Austria, Finland, France). In such cases special schools still exist as special schools and receive children as well on a daily basis (if the family lives nearby) or on a residential basis. Usually these special schools have also the function to give support to mainstream school who have visually impaired pupils in inclusive education. In some cases (France) pupils from special schools may be partially integrated to a nearby mainstream school.

In the case of inclusive education the pupil is usually the only one visually impaired children of the classroom, and the school gets some support. The support may be given by existing special schools, or independent services for supporting inclusive education (France). The support includes in all cases support for production of specific material (Braille, tactile documents, etc.). In most cases the support includes a teacher assistant at least several hours a week, who gives support to the teacher according to the need of the impaired pupil. In France the support is limited to production of documents and special education (mobility, Braille, daily living) outside the classroom.

Nevertheless some limitations exist. For instance in Austria the families have the legal right to attend mainstream school in primary and secondary school only. After that it is still possible but depends on the good will of the school.

In France the priority is supposed to be given to inclusive education and the law gives the right to any children to be in mainstream school, but does not give any mean to the family to make it possible. Then it depends very much on the good will of the school. Additionally a “commission of special education” decides if the pupil can attend mainstream school (and mainly special schools are represented in this commission). If we consider additionally the limitation of support provided to the mainstream schools mentioned above, the result is that if a lot of partially sighted pupils with slight sight problems are integrated, the large majority of blind pupils are in special schools.

b. Segregative education is the main situation

The second situation in Europe is the situation where most children attend special schools. It is still possible that in isolated cases some pupils attend mainstream school but they won't get any support and therefore it is limited to extremely bright students.
In the Micole study it was the situation of all pupils interviewed in Scotland. It is the same in Ireland and several other European countries.

c. Mainstream education is generalised

Sweden has chosen total inclusive education since a more than 20 years now. All children attend their local school (except deaf who are considered to need to gather together in order to develop their sign language which is regard the primary language of the deaf). Therefore handicapped children are most often the only one handicapped pupil of the classroom, and often of the school. In each case the teacher had the help of a teacher assistant. The situation is similar in Italy.

8.4.2 Special Equipment available

In each country students have access to Braille material and Braille mechanical typewriter (like a Perkins Brailler). Additionally, in most cases the pupils have access to computer with Braille output (Braille printer and/or Braille refreshable display) and ink printer (to print in black). Nevertheless some differences exist. In Finland the computer access starts grade 3. In France it is more complicated since special devices are provided to children in inclusive education but very few blind children are integrated. In special schools it depends on the school and the success in getting funding from various sources (including charity). Usually pupils from the secondary school have access to Braille devices, and use floppy disks or USB memory keys to carry documents. In Sweden each blind pupil receives a Braille device since the beginning of primary school.

Additionally according to the kind of group works considered in the study, pupils have been provided with different other material. In Finland and Sweden as the participants were younger they could have access to Abakus, tactile graphics (maps, pictures), wax material, special rulers, rubber drawing pads, clay and all sorts of hobby material like pieces of cloth, wood and paper, other material produced by the personal assistant.

In Scotland the older students valued computers a lot for working and for social purposes. Computers were mostly used for word processing but also for audio games and communication with tools such as email and MSN messenger. MSN messenger was highly praised by all participants who had used it. The Internet played an important role in work (for research), entertainment (games, news, sports information) and communication. Keyboards as well as Braille displays are used. Screen magnifiers and screen readers (JAWs) are used.

8.4.3 The group work situations

The group work situations are also very different in the different countries. One reason is that the kind of teaching is very different. For instance group works involving a group of 4-5 pupils happen very often Swedish schools, while it's very rare in France.

In most cases the kind of group works is the following. The group can be set by the teacher or chosen by the children themselves. The group gets a task and split work to do between the members. Finally they discuss together to combine the results they all have collected. The task is either given in text to each member of the group or only once which is read by one of the members to the others. The topics are various: natural sciences, chemistry, physics, resolution of maths problem, geography, even religious, Finnish (in Finland), handicraft, even religious matters (Austria). The results expected are presented as text documents, posters, handicraft or oral presentations (then the group decides for a spokesman).

In Sweden the group may have the possibility to define activities to experiment in a laboratory session. In several cases (Sweden, Scotland, Austria) the group has to search for information about a certain topic, from various sources (books, internet, etc.), and then to share this information together and to write a document summarising their results.

In France work in a special classroom was assimilated to group work since the class were small enough (around 5 pupils). Nevertheless it's more individual work made together since each pupil has the same task and they discuss together and with the teacher to progress. Another case of group works observed is outside the classroom, when classmates collaborate together with the purpose of explaining an exercise or notes taken during a lecture (case of mainstream school).

In all cases the communication during the group work is mainly verbal and text based. The only instance of non-text based collaboration considered in the study was in development of accessible tactile diagrams in Scotland. If a diagram was being converted from visual to tactile form, one participant would collaborate with a sighted peer to ensure that the tactile version conveyed the information in a useful form.

8.4.4 Group work difficulties

Difficulties mentioned relate mainly to textual matters. First it is too long too read in Braille (because of Braille reading of because of the computer when the document is long, like a big book). Additionally the visually impaired pupil has difficulties following the discussion when his reading is not finished and then misses some of the things that happen in the group work.

Reversely when the visually impaired pupil writes on the Braille, it's difficult for the sighted students who have only access to a small portion of the text at a time. Indeed Braille devices used in school often have an internal screen showing the line present on the Braille display (usually between 18 and 40 characters).

With verbal communication, the visually impaired pupils miss mimics and gestures of the others and the pupil therefore misses social cues that might be necessary in order to understand what is going on.

About the topics, abstract phenomena in chemistry and physics are hard to understand.

Finally it happens that some problems of jealousy appear because the visually impaired has access to computer and devices some others would like, or because the got the impression that the visually impaired pupil is somehow preferred by the teachers or has some advantages in performing tasks because of personal assistance.

8.4.5 The visually impaired children's feelings about group work.

Feelings from the visually impaired pupils are various. Some of them enjoyed group work particularly while others did not like it so much.

The reasons why it was much appreciated are the following:

- group work is rewarding (from a Swedish pupil)
- it is more fun to solve a task in dialogue with others
- it is easier to solve tasks because each pupil did not have to do everything by himself or herself
- they get to know other pupils better

- some of them liked presenting group work and were good at explaining things

Then, here are some reasons given by visually impaired who did not like group works

- one child thought that she got to do less work than she wanted when she did group work than if she worked by herself.
- one of them thought that the others were not really conscious of her and often left her out.
- the tasks that they were given are not very interesting

In the French study it was reported that to work in a group is the same thing as to work alone we just speak more loudly. It can be explained by the kind of group works that the French pupils experience that was described above.

8.6 Conclusions

According to the studies reported here, the blind pupils are not always included optimally when doing group work. Thus, the visually impaired students do not take part in the same task as the sighted students, their task of work are not being very interesting, some feel themselves completely excluded from the groups, or certain students do not wish to try to work with other classmates because the difficulty that could generate more work load (problem of data exchange).

When the visually impaired students are involved in collaboration they can be confronted with various problems of searching information (too slow computer, no accessibility of the Web pages), the difficulty of exchanges of sharing data (the graphic part of the Braille computer being too small, graphic elements not being accessible).

In parallel with the difficulties that the blind pupils in the working group can have, we think that it would be interesting to take into account what the pupils particularly appreciated. Indeed we think that these aspects must be taken into account in order to create some useful functions for future technical learning tools. These aspects are:

- All children liked to build things in other materials and also found group work that involved that kind of activity the most rewarding. Such materials could be clay but also wood or paper and all kinds of other materials.

- A student enjoys having swell paper graphics; e.g. one pupil mentioned that in physics, he received some graphics when they were learning about optics. This was very helpful for him in order to picture what they were talking about. A student also got a model of an atom so that she could touch and feel he enjoys these lessons very much.

These reflections of pupils show that it could be useful to produce a technical tool that makes it possible to grasp and understand a text as well as 3D graphics. Thus this tool will have to have a great graphic part so that visually impaired children can share their work with their classmates or the teacher. A haptic input/output device that makes it possible to visualize and grasp 3D forms thanks to the return of force feedback would be a good solution.

Finally the importance of collaborative tools allowing visually impaired pupils to work with their sighted peers is stressed. Indeed such tool should allow easy share of documents on Braille display and on the screen, the possibility to drive the screen from the Braille view and vice versa. This tool should allow the visually impaired to take notes and to show them to the others, and to write the report with the others, while they can see on the screen what he/she is writing. It should also allow the sighted to write and allow the visually impaired to access it on the Braille display.

9 General Guidelines from Empirical Studies in WP3

Based on the studies reported in this deliverable, the following general guidelines can be established.

- *Provide the users with representations that are similar enough to support the collaborative tasks*
- *Provide feedback on other people's activities in a collaborative environment*
- *Provide support for both getting a quick overview of the shared workspace and to get detailed information about a subset of the workspace*
- *Provide support for multiple interaction devices*
- *Fixed objects provide good navigation cues and support movement and re-localization of objects*
- *Provide means of recording and playback of trajectories in the haptic space*
- *Make the playback as customizable as possible, with possibilities to set speed in order to explore details.*
- *Design the collaborative tasks to minimize imbalances in initiative, resources and perception.*
- *Trajectory playback is an effective complement to a verbal description of a complex shape.*

10 Discussion and Conclusions

The work in Work Package 3 has during this second year focused on how well our designs of shared applications work when visually impaired and sighted pupils collaborate using them.

Based on the extensive results from the field studies year one a number of requirements were formulated. We took these requirements under consideration during the prototyping workshop when the design of collaborative applications was discussed. The aim then was to meet the most important requirements in the development of the prototypes that was to be evaluated the second year.

After discussions in the workshop we realized that it was important to create shared workspaces in order to avoid parallel work processes where the blind pupil is not included as much as they want to be. All the application has managed to meet this requirement.

Evaluations made this year show that this aspect is rather tricky to achieve. Both the availability of input devices and to what extent all pupils in a group has access to different information has consequences for the inclusion in group work. In the evaluation of the geometry application (KTH) for example the blind pupil had one Phantom whereas the two sighted pupils had to share one Omni. This resulted in one of the sighted pupils being dominant over the other so that one of the sighted pupils was a bit left out. Also in the evaluation by UTA of the application "Planetary system" it was found that even though collaboration went well, the fact that the blind pupil had a Phantom had effects on the social dynamics in that pair. Another aspect that is important for the degree of shared representation of a space is the design of the actual virtual environment. If the changes that people do in a virtual environment, like moving an object to a new spot, is not noticed by all pupils in a group the "sharedness", or with another word common ground, fails.

Another requirement was that it is as important to make it possible for the visually impaired pupils to produce information, as it is to support consumption of information in order for the child to be able to contribute in group work. This requirement was met in both the Collaborative gesturing (UGLAS), and the Cube moving (KTH) and to some extent the Auditory drag and drop prototype (KTH). In the Collaborative gesturing prototype, the visually impaired person could draw different shapes and was guided in this by a sighted person that could physically, apart from verbally, describe a shape. In the Cube moving prototype, the blind pupil could lift cubes and place them in order to build shapes. Also in this case a grab function made it possible for the sighted and the blind pupil to hold an object at the same time. The sighted pupil, or for that matter the blind pupil, could in this way guide the other to a certain spot in the shared environment. Also in the Auditory drag and drop prototype, the blind person could take and move objects.

The physical guiding functions that seem to be important in a number of studies as a complement to verbal coordination is an astounding discovery, that was not included in the initial requirements. The guiding behaviour is very intuitive and informative and useful for coordination.

The collaborative studies made this year have already been very informative and will be a good base for the final work year three. The fact that partners involved in these studies about collaboration and communication also take part of Work Package 4 that is responsible for the technical platform is very important. One result of this work is that many parts of the technical platform are already being transformed into collaborative environments. The collaborative aspects will therefore have a good chance of being realized in the final applications in a good way.

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