IST-2003-511592 STP

MICOLE
Multimodal collaboration environment for inclusion of visually impaired children

Specific targeted research project

Information society technologies

Deliverable D15: Final evaluation report

Due date of deliverable: 31.08.2007
Actual submission date: 15.10.2007
Resubmission date: 3.3.2008
Version 1.1

Start date of project: 1.9.2004 Duration: 36 months

Name of the partner responsible for the deliverable: Lund University - ULUND

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Version 1.1 / 19.12.2007

Summary

This deliverable reports on the final evaluation conducted in the MICOLE project, aiming at assessing the final architecture as well as the application prototype demonstrators. Five different applications have been successfully evaluated during 2007 by in total 63 persons. Two applications are built on top of the MICOLE architecture and the others would equally be possible to build with MICOLE architecture parts. All the applications have utilized collaborative functions tailored for each use situation. Four of the applications have been evaluated in schools for educational use in the school subjects: mathematics, astronomy, geography, literature, and science (electrical circuits). In general the students are able to complete the tasks and both students and teachers find the applications useful and valuable.

Updates: for the second submission tables 1.1 and 1.2 together with the chapters 5 (MAWEN) and 6 (King Pong) have been updated. Appendices 4A-4D (belonging to chapter 6) have also been added.

1. Introduction

This deliverable reports on the final evaluation conducted in the MICOLE project, aiming at assessing the final architecture as well as the application prototype demonstrators.

1.1 Background and objectives

The evaluation of the MICOLE architecture and the prototype applications has been an ongoing process during the entire project. Reference groups and individual pupils have been part of the design-evaluation loop, of which the individual test descriptions can be found in deliverables for WP 2 and WP 3.

The final evaluation was conducted during the last 8 months of the project, aiming at assessing the final architecture by evaluating the final application prototype demonstrators, as well as evaluating the final application prototypes themselves. The evaluated prototypes have been:

- The AHEAD – an Audio-Haptic line Drawing Editor and Explorer
- The Solar system application
- The Electrical Circuits application
- The MAWEN – a mathematical Braille parser
- King Pong – an auditory game

Two of the application demonstrators are built on top of the MICOLE architecture: the Solar System and the Electrical circuit applications.

1.2 Methods

The main project aim has been to create *a system that supports collaboration, data exploration, communication and creativity of visually impaired and sighted children.* In practice, one arena for collaboration, communication, data exploration and creativity where sighted and blind children can meet are schools where children with visual impairments are integrated in classes with sighted children. Therefore, the scenarios chosen, and the applications developed are mainly intended for school use. The applications and the use scenarios in the final evaluation have been planned in collaboration with teachers and the final evaluations were also supposed to take place in schools during normal school work. However, this situated approach to evaluation brought forth some practical obstacles such as the problem obtaining permission to make video recordings and take photos, and thus only 4 evaluations have been conducted in integrated classes within normal subjects at normal school hours during a busy lesson. Other evaluations were conducted at school in a separate room outside of normal class hours (the King Pong evaluation was conducted outside school altogether).

All scenarios and applications have been designed to support collaborative use. In the final evaluation the collaborative use has been used for task collaboration between pupils (one sighted and one with visual impairment) or more as a possibility to obtain help by a teacher that could guide and show the pupil how to solve tasks.

The test procedure has been similar in all sites. The pupils have been allowed to do some training with devices (PHANToM for haptics, VTPlayer for tactile cues) before the actual test. The test has been a school task (except for King Pong) and the scenario has been school like with a pedagogic goal to learn something or accomplish a school task. After the test the pupils have been interviewed. The interview questions have been adapted to the different tasks and are not comparable in detail. The test occasions have been video-recorded and observed with focus on task completion, navigation and exploration problems and behavior, and collaboration.

1.3 Test participants

The tests and their participants have been spread out in 6 countries and with 6 partners. Both teachers and pupils have been involved in the final tests. The main participants have been the pupils with blindness or low vision, and in some cases they have working individually and in others they have collaborated with a fellow pupil. In the cases where the pupils worked individually, the teacher could use the collaborative system to guide and help the pupil with the task solution. The visually impaired pupils have in some cases also been involved in the design-evaluation phase. This implies that during the final evaluation they were not all novices to the haptic, tactile or auditory display systems, which is advantageous since we want to investigate implications of long-term practical use rather than how a novice user reacts to the system the first time(s).

	AHEAD	Solar	Electrical	MAWEN	Pong	Total
Blind pupils	3	1	3	15	5	27
Low vision pupils	4	3	10	4	7	28
Sighted pupils	5	4	0	0	0	9
Teachers	2	0	1	8	1	12
Total	14	8	14	27	13	76

Table 1.1 Participants involved in final test of the different applications, by category.

Age August 2007	**AHEAD**	**Solar**	**Electrical**	**MAWEN**	**Pong**	**Total**
7-12	4	8	4	1	2	19
13-18	8	0	9	12	10	39
Adult	2		1	14	1	18

Table 1.2 Participants involved in final test of the different applications, by age.

The grand total of participants in the final tests is WW, spread out over different age groups (see table 1.2). Six of the students in the ULINZ test were adults which explains why there are more adults than teachers.

2. AHEAD - Audio-Haptic Drawing Editor And Explorer in 2D

Certec, Lund University – ULUND
Nada, KTH – KTH

2.1 Executive summary

During spring and summer 2007, 5 pairs of pupils and 2 pairs with one pupil and one assisting teacher have been evaluating the drawing tool "AHEAD", in school tasks situated in schools. For 5 of the tests, individual tasks based on the AHEAD functionality have been created in collaboration with researchers and the pupil's teachers. The 2 remaining tests used material from one of the individual tasks created. All users have managed to use the application as intended in their specific task.

2.2 Background and objective

Based on the initial interviews done in the project (reported in D1) in combination with the feedback received at the first focus group meetings, we decided to implement a general purpose 2D graphics editor and explorer: the AHEAD - Audio-Haptic Drawing Editor And Explorer. AHEAD has been iteratively designed and evaluated by our focus group during the project.

2.3 Application

The Reachin 4.1 API for haptic interaction is needed to run the application, along with FMod Ex 4.04.30 used for non-speech sound and Microsoft SAPI 5.1 for speech synthesis. A PHANToM device is used for haptic feedback and control, and a mouse can be used for non-haptic control of the program.

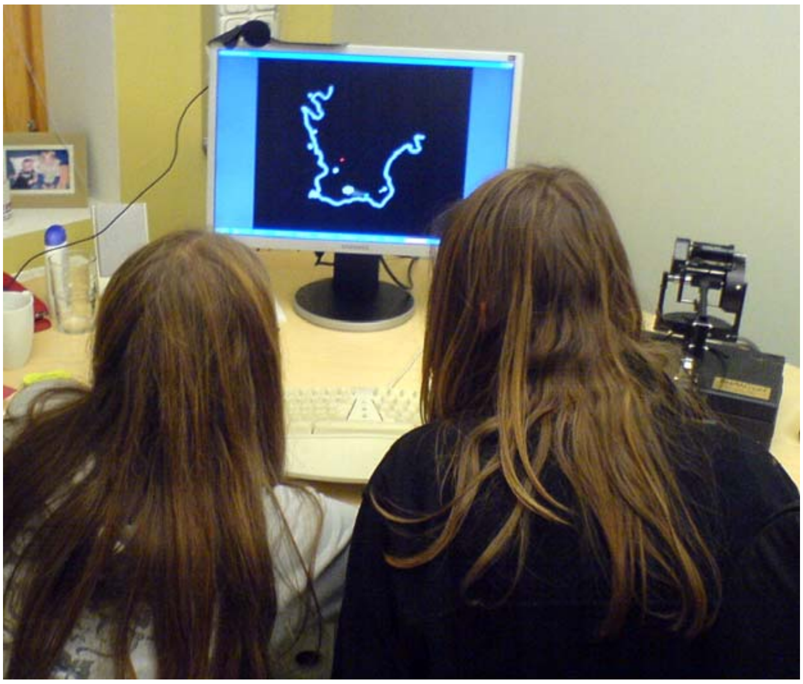

Figure 2.1 Two pupils collaborating using the AHEAD application making markings on a map of the Scanian region in Sweden

The virtual environment consists of a virtual sheet of paper. The application can be used in two different modes: one for editing and one for exploring relief drawings.

In explore mode the users can explore text tagged relief drawings. The haptic image is produced as positive or negative relief. The drawing is represented on the screen as a grayscale image – a positive relief is seen as black, and a negative relief is seen as white. The paper color is grey. The users can select drawn objects by touching them with the PHANToM pen or hovering over them with the mouse cursor. When selected, the text tag for the line is spoken by the TTS engine. The mouse user can guide the PHANToM user by a pulling force that drags the PHANToM pen tip to the mouse cursor position. Similarly, the PHANToM user can drag the mouse cursor to the PHANToM position.

While in edit mode the PHANToM user can create and edit drawings. Drawing lines is done by pressing the switch when in contact with the paper. The mouse user draws while pressing the left mouse button. The PHANToM user can feel the lines while drawing. Drawn lines or figures (objects) can be manipulated in the different ways; moving, resizing, copying, pasting and deleting. Additionally, text tags for the lines and shapes can be changed, and shapes can be transformed into straight lines, rectangles or circles. The manipulation tools are fitted with feedback sounds designed to resemble a real world manipulation of similar nature. E.g. the copy function sound effect is a camera click.

Drawings can be saved and loaded with the application, using the applications customized MICOLE file format ".mcl". The format includes the objects and the text captions for them. A ".png" import function is available. The files imported must be grayscale and exactly 256*256 pixels.

2.4 Evaluation

The AHEAD application is in itself a multi-purpose application that can be used both for exploring prepared relief drawings and to create them in any school subject needed. Teachers and researchers have collaborated in planning and preparing a task and material for a school subject fitting the class and the individual pupil, and the tasks and the application have then been evaluated in a school setting.

2.4.1 Participants

A reference group with 5 participants aged 11 to 17 yrs has participated in the entire project. The pupils are fairly well trained using the PHANToM, having used it at 3-6 reference group meetings, and have also participated in the iterative design of the AHEAD application. Their parents and/or siblings have also participated in the iterative design. Descriptions of the iterative design and evaluations can be found in deliverables D4 - D7 and in [1]. 4 of the pupils participated in a qualitative evaluation with a prototype of the AHEAD application very similar to the final application. For the final evaluation, the pupil's teachers and teaching assistants have participated in the planning and in the evaluation lesson at school. In three of the evaluation cases the pupil collaborated with a class mate, and in two cases the teaching assistant used the collaborative feature of the application to instruct the pupil. Furthermore, a group of 3 pupils outside of the reference group participated in the final evaluation. These pupils also had no prior experience with the PHANToM and also not with the AHEAD application.

3 of the 5 pupils in the reference group have residual vision. Only one of them used it while working with the evaluation task.

Pupil	Age	Residual vision	Number of ref group meetings attended	Previous experience with last prototype of AHEAD app	Total PHANToM use experience prior to test
1	11	Used	5	No	1 hour
2	12	Not used	6	Yes	1 hour
3	12	No	6	Yes	1 hour
4	15	Not used	6	Yes	1 hour
5	17	No	5	Yes	> 3 hours
6	12	Not used	--	No	None
7	15	No	--	No	None

Table 2.1 Summary of visually impaired pupils and their previous experience of PHANToM use and use of the AHEAD application

2.4.2 Context

All pupils attend normal schools and are integrated in a class with sighted pupils, but the classes are somewhat smaller than normal classes (except the high school class for the 17 year old pupil). The schools are situated in urban areas in Sweden. 4 tests were conducted during normal class time and in the subjects according to schedule. For pupil 2, the evaluation was performed in the special time assigned to the pupil to learn special skills needed for living with blindness, e.g. navigation training. Pupil 6 and 7 performed the tests at school, but in a special classroom and outside of the normal curricula.

4 pupils used the application in the explore mode only. That means they used the application to access a relief picture with text tagging to be able to access maps (3 pupils) and an overview drawing of a theater (1 pupil). These 4 tasks were focused on understanding the relative spatial positions and relationships in the representation.

3 pupils used the application as a drawing tool in a task focusing on learning to use a mathematical language when explaining composite geometry figures to a class mate. The task was prepared for use with the class of pupil 4 by their mathematics teacher, and also evaluated at a mathematics lesson there. After the evaluation in that class, 2 additional pupils have participated in a test with the same task.

Pupil	Collaborator	School subject	Mode	Interaction
1	Teaching assistant	Geography	Explore	PHANToM, mouse, TTS and screen
2	Class mate	Navigation training	Explore	PHANToM, mouse and TTS
3	Teaching assistant	Geography	Explore	PHANToM, mouse and TTS
4	Class mate	Mathematics	Edit	PHANToM, mouse and TTS
5	Class mate	Literature	Explore	PHANToM, mouse and TTS
6,7		Not in normal subject	Edit	PHANToM and TTS

Table 2.2 Summary of users, school subjects, modes and interaction types used in tests

2.4.3 Procedure and tasks

The tasks were planned by teachers and researchers in collaboration. The teachers were invited to try the AHEAD application and to discuss possible subjects and tasks that would fit. Since it is quite a challenge to try to envision the possible use scenarios for the teachers, the researchers had prepared a couple of demonstrators showing map use and geometry use, but the application was also showed in the mode where you can create a drawing from scratch. The demonstrators were chosen based on an early interview (D1) where many participants mentioned the need for accessible maps and access to graphics. The chosen subjects can be seen in table 2.3 above. The material for the 4 tasks that focused on using the AHEAD application for accessing graphical content can be seen in figures 2.X to 2.W. These tasks were all similar in one way since they used the explore mode of the application and did not allow any editing.

However, the different drawings used somewhat different abstractions to convey information. The three maps where quite different from another, one being a country map without any separations in different regions or states, one being a continent map where the different countries needed to be marked, and one a small scale map of a school yard where obstacles and ground features were the most important things. This led to three different strategies in creating the maps: the country map is a map with only negative relief information; the school yard map is a positive relief map, and the continent map is a combination of both.

The preparation of the material was done in different steps. First the original graphics were prepared. In 3 cases this meant to download and use some graphical material as base material, e.g. free maps on the Internet. For the school yard, the map was made from scratch, visiting the school yard and making first a hand drawing and then a drawing in Adobe Illustrator, since the official map of the school was not updated in a long time. The graphics were converted using Adobe Photoshop to line drawings in grayscale, and then inverted to make the lines white which in the AHEAD application means they will be rendered as negative relief (grooves). The graphics were also cropped to 256*256 pixels. Then the prepared grayscale files were loaded into the AHEAD application as a background picture and the outlines and figures that were important were filled in using the edit mode. Objects were also text tagged. When the copying part was done, the background file was removed, and what remained were the important features with text tags that the TTS system would speak when objects were selected.

Task for pupil 1

The test was conducted in a fifth grade class in the subject geography. At the test occasion, 16 pupils were present in class. A low vision pupil is integrated in the class, having a specialized work station with a computer equipped with Braille display, speech synthesis and two CCTV cameras for watching the teacher, whiteboard, pull-down maps, and enlarging visual material such as paper maps.

The task was developed in collaboration between the teacher, the teaching assistant and the researchers. The teachers were concerned that the pupil in their class would not have any good use for the AHEAD application since the pupil has some residual vision, but they nevertheless agreed on trying it out. The pupil is quite skilled at drawing by hand, so it was agreed that the material should give the pupil access to some graphics that usually were a challenge to understand.

The learning task chosen was to learn to interpret maps and learn about the geography of the European part of Russia. The specific task for all pupils was to draw a simplified map of the country, featuring the most important parts such as mountains, rivers and major cities. The sighted pupils worked with a regular map book and an outline map where they were supposed to fill in the important features.

Fig 2.2 Example of finished map of European Russia made by sighted pupil (left). Finished map of Iceland based on a tactile map made by visually impaired pupil (right) made at a previous lesson.

The test setup for the visually impaired pupil consisted of a PHANToM OMNI, a laptop running the program and acting as screen and keyboard for the pupil. The teaching assistant used the mouse for guiding and showing the pupil features on the map when needed (fig 2.3).

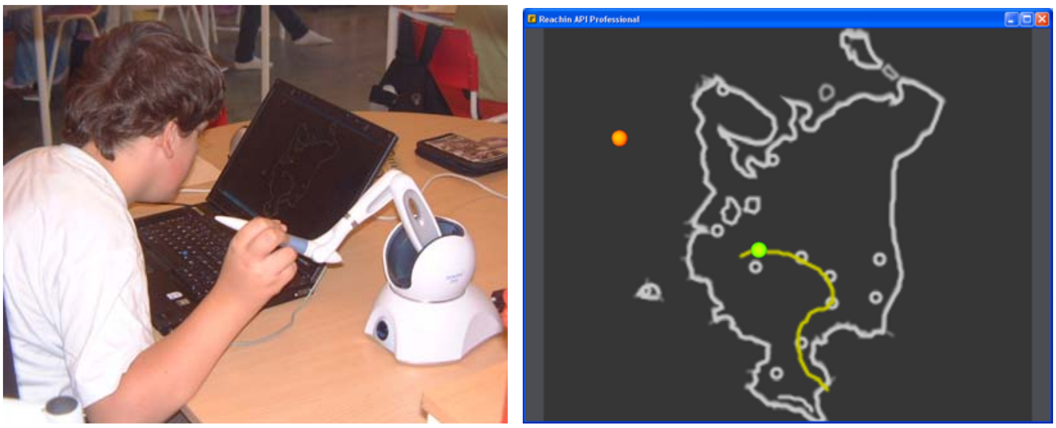

Fig 2.3 Left: Test equipment in the classroom used by pupil. Right: Screen dump of map used by the pupil featuring the European part of Russia.

The AHEAD application was loaded with a customized map of the European part of Russia, prepared by the researchers and drawn with the AHEAD application. The map was drawn in negative relief, featuring TTS captions for borders to other countries, cities and major mountain ranges and the river Volga, and the two largest lakes. The larger cities also had information about size of the population.

The pupil used this map as a substitute for looking in the map book through the CCTV, which is the way the pupil usually performs the task, inducing problems such as glare and problems with overview. Also having to read the text with the CCTV is a problem, and to discern exactly what feature the text is describing, since the text normally is very large compared to e.g. a city marking.

The pupil had a tactile map of the outlines of European Russia to make a simplified map. The pupil used markers and crayons to draw and write on the paper map.

The visually impaired pupil was allowed to practice about 5 minutes with the application before the lesson. The pupil is well used to the PHANToM (approximate use time 30 minutes), and has tried out previous AHEAD application prototypes at 2 previous occasions, however not with the specific task and not with the guiding function.

Task for pupil 2

The test was conducted in a sixth grade class in the subject geography. A low vision pupil is integrated in the class, having a specialized work station with a computer equipped with Braille display, speech synthesis and also CCTV cameras that, however, are not used.

The task was developed in collaboration between the teacher, the teaching assistant and the researchers. The teachers were very concerned that the pupil had difficulties accessing some material (like maps and geography information) independently. The pupil was relying very much on that the teaching assistant made verbal descriptions about the graphics. Therefore, the researcher prepared and drew a map of South America in the AHEAD application for use in a geography lesson.

The learning task chosen was to learn to interpret maps and learn about the geography of South America. The specific task in the lesson for all pupils was to make a simplified map by hand of the continent, with major mountain ranges, lakes, countries and capitals.

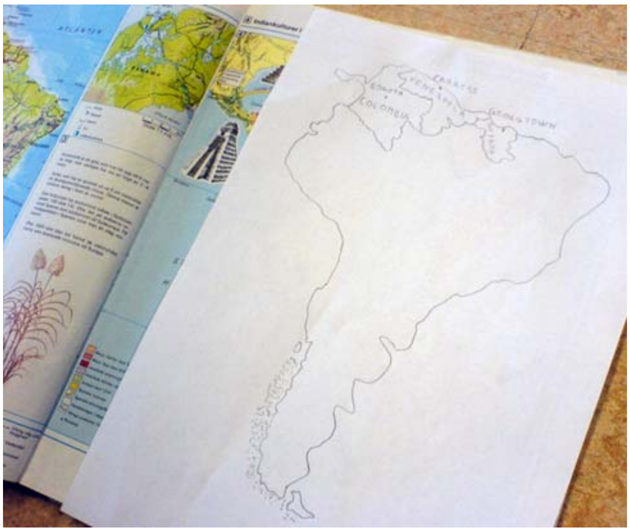

Fig 2.4. Hand drawing of South America map made by sighted pupil in class.

The visually impaired pupil usually worked with the teaching assistant, who described the geography verbally and a tactile map for reference. There were markings on the tactile map, code letters that marked important features, and the pupil usually typed in the code letter and the names that the code letters marked in the computer.

At the particular test session, however, the pupil was instead working with a sighted classmate, collaborating on the task. The classmate would make the markings on the tactile map, while the visually impaired pupil was exploring the map (see fig 2.5) in the AHEAD application and telling his class mate what to write down.

Figure 2.5 Screen dump of map used by pupil. Map of South America, with country borders, capitals and surrounding oceans marked in negative relief with text captions. For Brazil and Argentine the text captions also included country specific information (e.g. population, language and currency information). Between the country borders was a positive relief, separating the borders from each other to make it possible to trace an outline.

Fig 2.6. Tactile map used, with small Braille markings for every country

Task for pupil 3

This pupil was the only one who did not use the AHEAD application in class, but it was used for navigation training. Because the visually impaired pupils are integrated in normal schools in Sweden, the schools are also taking care of e.g. navigational training together with the "syncentralen" - a clinic that prescribes assistive technology and performs ADL (Activities of Daily Living) training for people with visual impairments. Usually the navigational training was performed with a tactile map and by walking repeatedly the paths that the pupil needed to learn.

The teaching assistant had an idea on making the navigational training more interesting by finding a motivating target (the local bakery), and also by using the AHEAD application to display the map. Therefore a kind of treasure hunt was implemented. 3 detailed maps of the path from school to the bakery were prepared with the AHEAD application.

Figure 2.7 Detailed map of school yard with outlines of different surfaces and objects like grass, pavement, trees, hedges, poles etc.

The pupil was to explore every map, one at a time, so that when the a map (see e.g. fig 2.7) was explored and the treasure on that map was found and the pupil felt confident enough to remember the route, the pupil was supposed to travel by foot unaided to the treasure in the real environment. The teaching assistant was allowed to give verbal hints referring to the map, but not helping to direct.

Task for pupil 4

The test was conducted in a ninth grade class in the subject mathematics. At the specific test occasion, 12 pupils were present in class. A low vision pupil is integrated in the class, having a specialized work station with a computer equipped with Braille display and speech synthesis.

The learning task in the particular lesson was to practice using geometrical mathematical language, i.e. words like “rectangle”, “sphere”, “angle” and “diagonal” to describe a composite geometry figure to a fellow pupil. The teacher started the task by describing it verbally to the pupils, and also drew an example image of a composite geometry figure on the white board while also in detail describing the figure.

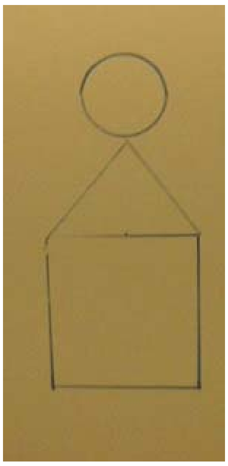

Fig 2.8 An example picture drawn by teacher on white board.

The teacher also paired the pupils together. The sighted pupils were instructed to use paper, pencil and a ruler, and the visually impaired pupil and a fellow pupil were instructed to use the drawing program. The test setup consisted of a laptop running the program and acting as screen and keyboard for the sighted pupil who also was using a mouse for input. The visually impaired pupil had a separate keyboard attached to the same computer, a screen, headphones and the PHANToM OMNI. Half of each screen was blinded by a piece of cardboard to prevent the pupils from seeing each others drawings.

Fig 2.9 Test equipment in the classroom – for the sighted pupil (left) and for the visually impaired pupil (right). The visually impaired pupil did not have use for the screen but the screen picture was displayed for documentation reasons (video recording).

The drawing program was adapted in a very minor way, by loading a file with a subtle grid in positive relief, and a middle line with the spoken caption “Stop, middle line”. The pupils had one part of the virtual paper/screen each to draw on and the middle line was not to be crossed until the last phase of the task. There were three parts to the task; first, one pupil would design a composite figure in the drawing application (without showing it to the other pupil); second, the same pupil would describe the figure to the other pupil who would try to make a copy based on the description; third, the pupils would together compare the copy to the original figure.

The visually impaired pupil was allowed to practice about 10 minutes with the drawing application before the lesson. The pupil is well used to the PHANToM, and has tried out the drawing application at 3 previous occasions, however not with a grid and not with the specific task. While practicing, the pupil was not informed about the exact nature of the task in the lesson, but was introduced to the drawing tools and the grid. The sighted pupil was given a 2 minute introduction when the lesson had started.

Task for pupil 5

The test has previously been reported in D10. The pupil attends a High School program with special focus on aesthetic subjects like theater performance and music. The particular lesson was a literature study where the task was to study a Shakespeare play and to plan where to place the actors in the different scenes in the play using a drawing of the Shakespearean Globe Theater, while working in pairs. The visually impaired pupil could choose between different drawings of the Theater prepared for the AHEAD application to access the graphics, and worked together with a classmate in the task.

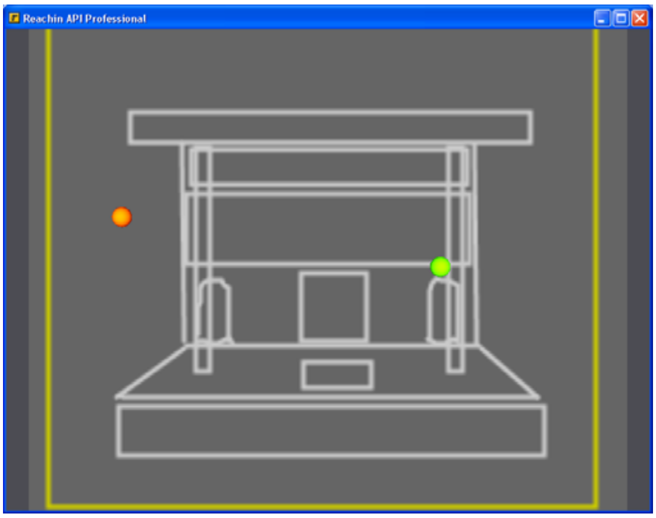

Figure 2.10 A simplified drawing of a Shakespearean theatre. The major part such as pillars, main stage, balcony, trap door, valves etc. were marked with text captions.

Collaboration tests at KTH (2 pairs of pupils)
The participants consisted of two pairs, with one visually impaired pupil and one sighted classmate in each pair. In the first pair the visually impaired pupil was 12 years old and had experience of using a phantom once before, but hardly remembered anything about it. In the second the visually impaired student was 15 years old and had never used a phantom or any other haptic device before. The pupil in the first pair was visually impaired with some residual vision; the pupil in the second pair was completely blind.

The two tests were conducted at the pupil's schools (secondary school) during regular school hours. However, both tests took place in a separate room and not in the regular classroom. The equipment and task was similar to that of the test with pupil 4 above, however, only one computer screen was used (for the sighted pupil) and with the pupil having low vision a Desktop PHANToM was used.

The task was divided into three parts was the same as the one for pupil 4 above. The test session started with the blind pupil getting to know the haptic environment and how to draw and explore using the drawing application. After this, the two pupils were instructed together about the task, and they were instructed to start when they felt ready. Throughout the test the participants talked to each other, and the session leader gave advice on the interaction with the device.

2.4.4 Interviews

Post-test interviews were held by the researchers participating in the test. The participating pupils and the teachers were interviewed according to the interview questionnaire in Appendices 2.A and 2.B. The answers were sketched down on paper by hand to enable a fast and easy overall analysis, but also sound recorded making it possible to do a deeper detailed analysis. The persons interviewed in each test varied somewhat according to the task and collaborator and the teaching situation. The table 2.3 shows the persons interviewed for each visually impaired pupil who participated in the test. The teaching assistants who were collaborators were interviewed as teachers and not as collaborators as such (the questions differed somewhat, see Appendix 1.A and 1.B). In the collaboration test performed at KTH a short interview was done with the participants, focusing on the experience of collaborating with the help of the haptic environment and also on usability aspects regarding the system.

Pupil	Collaborator	Head teacher	Teaching assistant
1	(Teaching assistant)	Yes	Yes
2	Class mate – yes		Yes
3	Teaching assistant		Yes
4	Class mate – yes	Yes	
5	Class mate – yes		
6	Class mate – yes		
7	Class mate - yes		

Table 2.3 Summary of interviewed persons at each performed test.

2.4.5 Measurements

Video- and photo-supported observation

During the different test, 2 or 3 researchers participated. One researcher was busy filming the progress of the work of the visually impaired pupil and his/her collaborators, while another was observing the overall work in the classroom, taking notes and pictures of the work done by sighted pupils. During filming, notes were also taken by hand, and some important times were measured. The third researcher performed the application startup and was supposed to help if and when the software did not function as expected. The collaboration tests at KTH (and interviews) were videotaped and transcribed word for word. Also, annotations of the video recorded behavior during the test sessions were made.

Logging

The application incorporates a logging function that takes samples of the PHANToM and mouse positions, logs user commands and selected objects in the drawing. The log files can be filtered to extract the important information for each task and individual test.

Recording of interviews

The interviews were recorded with either video or audio recorder.

Time measurements

Where relevant, task completion times were measured.

2.5 Results

2.5.1 General usability

We have conducted a usability walkthrough of the application based on Jakob Nielsen’s “Ten Usability Heuristics” [2], and also added some findings on general usability that arose during the final evaluation.

- *Visibility of system status*
  (-) In non-visual interaction, this is a major problem. The usual way to make “visible” system status in non-visual interaction is to convey the information by sound, which can be intrusive. You need to make a careful consideration of how much you need to display and whether the sound is to be continuous or sampled. After pilot tests sound feedback was mainly reduced to give feedback on actions.
- *Match between system and the real world*
  + The PHANToM pen is used quite similar to a normal pen when drawing (except that the switch needs to be pressed). No drawing will occur when the pen tip is not in contact with the paper.
- *User control and freedom*

+ Undo function exists.
- You can only undo the last action.

- *Consistency and standards*
  + There are few standards in the area. Sound pitch is used for size changes, and auditory icons are used for interaction feedback, which are reported to minimize memory load [3]. Standard words and standard save file dialogs are used.
  - Only TTS is used for text output, not a combination of TTS and Braille output as is common.
- *Error prevention*
  + The application is fairly stable, and run-time errors have been few during the final testing. One error has been corrected that caused the application to halt when mouse user and PHANToM user tried to guide one another simultaneously.
  - The user needs to be in contact with the virtual paper to draw. No warning is given if the pen looses contact with the virtual paper. It is also possible to slip off the virtual paper – no warning is given.
- *Recognition rather than recall*
  - The very word recognition implies the interface to be a visual interface. For practical reasons, commands are keyboard based, forcing the user to remember the keys or frequently invoking the help command.
- *Flexibility and efficiency of use*
  - Since the application is supposed to be used by both sighted and visually impaired users, more action should be taken to display commands for sighted users.
  - Novice users may need a frame around the drawing surface for reference and border. Otherwise users can fall off the surface.
- *Aesthetic and minimalist design*
  + As it is designed for blind or low vision users, the interface is very clean.
- *Help users recognize, diagnose, and recover from errors*
  - There is as yet no practical way of handling recovery from crashes, and there is also no saving of temporary files which would allow the user to return to a previous version, if the user has not saved the prior versions manually.
- *Help and documentation*
  + A help file (only text) can be displayed (read) by the TTS system. A sighted user can also manually open it with notepad or the like. The help file can be manually edited by removing unused commands and placing frequently used commands in the beginning of the file. This way, the help file will be shorter to hear through.

Stability issues

The application is fairly stable, given that it is a prototype. During the 5 school-situated test sessions conducted by ULUND, the application worked without malfunctioning in 4 cases out of 5. The one problem was possible to solve ad hoc by instructing the pupils to refrain from using the mouse guiding simultaneously with the PHANToM guiding in the test situation, and the rest of the test was performed without any crashes. The bug that created the crash was immediately corrected and the following tests were not affected. There may, however, be issues of efficiency or computer speed. In the tests at KTH the users experienced falling through the drawing surface more than once during the test. This is naturally very disturbing, but most surely a question of computer performance.

Overall satisfaction with system

In the interview questionnaire, the pupils and their teachers (for pupil 1-5) were asked if they would be interested in using the system for more school tasks (graded on a scale between 1 and 5, where 1 means "not at all", and 5 means "very much interested"). All pupils except one and all teachers rated the system with a 4 or a 5.

2.5.2 Exploration and navigation

Pupil 1 (European Russia map).

This pupil used PHANToM, audio and screen to interact with the map. The cursor on the screen was enlarged to enable this pupil to be able to see it. The pupil used the map as planned as a reference for drawing a map by hand with major features on. The pupil was especially pleased to be informed about the population of the major cities, as this feature is not given in tactile maps and is hard to understand in an enlarged paper map. The pupil was well able to handle the application with the map, and rated it higher when asked to compare it with the normal way of working with maps.

A problem was that the geographical names were displayed in TTS only, making it hard for the pupil to understand the names and their spelling. The teaching assistant asked the pupil to look for the correct spelling for some of the names in the drawn map book, unfortunately drawing attention from the task at hand and forcing the pupil to work with 3 media at the same time. The teaching assistant tried not to intervene, so the collaborative features were rarely used.

Pupil 2 (South America map)

The pupil collaborated with a fellow pupil. The visually impaired pupil used the PHANToM to explore the map, and the sighted pupil looked at the map, and made markings on a tactile map and wrote the country and capital names on a sheet of paper. The markings were small stickers with Braille numbers, and it was actually hard for the pupil to handle them, which forced the visually impaired pupil to wait.

The visually impaired pupil had quite large problems with the handling of the PHANToM. The force the user exerted to press against the virtual map was too hard, and the PHANToM OMNI device could not resist it, which can be seen in the log file. Although the pupil pressed very hard and at times penetrated the virtual surface with 2-3 cm the TTS information and the relative positioning of the pupils own hand conveyed the needed information. The pupil could tell the collaborator about the position in relation to the other countries or oceans, e.g. "Chile is to the left (west) of Brazil but to the right (east) of the Pacific Ocean".

At times, the collaborating pupil guided the pupil by dragging force or with oral information.

The major countries and their capitals were found fairly easy, however, smaller countries (i.e. French Guyana, Surinam and Guyana) were too small to handle, and the teaching assistant insisted on asking the pupil to find them.

Pupil 3 (School yard map)

There were 3 maps leading step by step to the last goal (the local bakery). The pupil started with the map that showed the first part of the path with a known school entrance and known features outside the entrance. The teaching assistant guided the pupil orally to different features in the map – both previously known places and other places not known to the pupil before. The pupil also explored the map freely, discussing with the teaching assistant and commenting on the features that were encountered. The pupil was told to search in the map for a spot with a treasure. When the treasure spot was found, the pupil and teaching assistant went through the best way to travel to the treasure. The path was then repeated until the pupil felt secure to find it in the real environment. Handling the PHANToM and the map environment seemed to be easy for the pupil, who used fairly small, controlled movements in the search for different features. This approach, however, made it harder to travel open spaces in the map.

The pupil then had to go to find the real treasure. The real distance from the entrance door was about 30 m. The teaching assistant was allowed to accompany the pupil and also give hints referring to the map. The treasure was found after hints and some discussion, but the pupil was about to go the wrong way while following an edge. The pupil also had to navigate on the way back to the school entrance.

Back in the classroom were the application was placed, the pupil worked on the next two maps in direct succession, since the time was about to run out. The teaching assistant also attempted to use the guiding function with the mouse dragging the PHANToM, but this disturbed the pupil's feeling of control and direction and the pupil asked not to be guided by force but rather by oral description. On the way to the end target (the bakery) the pupil was helped and hinted in order to feel that the task was accomplished.

Pupil 4 (Geometrical drawings)

The pupils both managed to use the application for the intended task in call. They took turns drawing and copying, the PHANToM user started 3 times and the mouse user also 3 times.

Looking at the resulting images (figure 2.11) we can see that the pupils have succeeded with the task - both have managed to understand the instructions and show this understanding by drawing a reasonable replica of the original (the drawings are not perfect, but they catch the essence of the design).

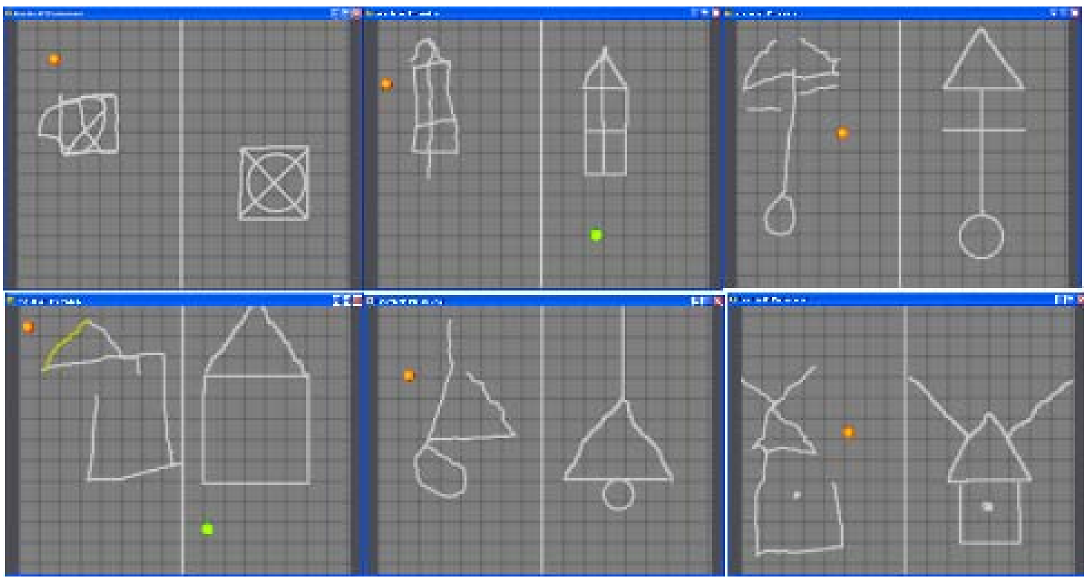

Figure 2.11 The pairs of drawings generated. In the top row, the mouse user (to the right) designed the original, while in the bottom row it was the PHANToM user that did this. The time order in these images are task 1,3 and 5 in the top row and 2,4 and 6 in the bottom row.

By analyzing the logged position information we have indications that the user does not have problems with disorientation, something which was supported by observations made during the test. The visually impaired PHANToM user seemed quite well aware of where things were, and did not appear to have any major problems getting lost within the workspace (despite the absence of any limiting box in the current version of the AHEAD application). One problem that did occur was that the user on one occasion accidentally erased the wrong line – something which shows that more feedback is needed for this type of operations. Apart from these two findings no major problems were experienced.

After completing the drawing, the pupils were allowed to check each others drawings. The sighted pupil lifted the cardboard to look at the visually impaired pupils drawing, and the visually impaired pupil was allowed to feel the sighted pupils drawing. One interesting finding was that the visually impaired pupil did not actively explore the drawing, but was guided around by the sighted pupil, feeling the gestures of the drawing.

Pupil 5

The visually impaired pupil and a collaborator successfully used the schematic drawing of the theater in their task to set the stage for the Shakespearean play they were reading (Macbeth).

For more information see D10, where the details of the test results are described.

Collaboration tests at KTH (2 pairs of pupils)

In both test sessions the pairs managed to perform the task that required them to take turns to draw a picture, explain it to the other that tried to draw a copy of the described picture.

In both pairs the visually impaired pupil experienced difficulties in knowing the limits of the drawing surface and therefore slipped behind it. Furthermore, in both pairs the visually impaired pupil accidentally pushed through the drawing surface. These two facts interrupted the pairs in their work in several ways. It was hard enough already to memorize what had been drawn during the drawing action and when the visually impaired pupil got lost behind the drawing surface they had to investigate what they had drawn already, and search for the place where they had just been before they slipped. During the task, they were not allowed to see or feel what the other person drew so the sighted person could not guide the visually impaired pupil verbally or haptically while he/she was drawing.

There was a big difference between the blind pupil and the pupil with some sight left in how easy it was to at all feel the drawing surface, and to feel the drawing action when using the Phantom. The blind pupil needed an approximately 20 minute long training period and repeatedly said that she did not like the environment. The blind pupil held the pen with both hands whereas the pupil with some sight left mostly held it with his dominant hand.

In both pairs using the keyboard in order to erase appeared to be easy. The pupils understood how to erase immediately and also used it rather effortlessly and fast.

The guiding function was not used very much but when it was used it worked rather well except that it was sometimes too fast and therefore pulled the pen from the visually impaired pupil's hand. One of the visually impaired pupils once initiated the guiding by asking the sighted pupil to guide him to a part of the drawing that the sighted had drawn.

2.5.3 Learnability

As described earlier, all the 5 pupils in the school test have tried the PHANToM a number of times (see table 2.1) and 5 have managed to learn to use it as a tool. One pupil still has problems using the PHANToM, but the same pupil has documented problems with fine motor control, but it seems that the pupil nevertheless could solve the task. All pupils stated that it took quite short time (5-10 minutes) to get into the task and to use the system as a tool.

Only one pupil had scheduled training time before the real test session. This was the pupil who was using the application for drawing (pupil 4). On previous occasions the pupil had not tried the application with a grid. The pupils were asked if they would have wanted to have more training before the test, and only one stated that the training was not sufficient.

The pupils were also asked if they thought that they were more fluent in the use of the system in the beginning or the end. We can see that this depends much on the nature of the task. In the beginning the pupils are also much more fresh and eager to work. After an hour school work they tend to be more tired and long for break.

Pupil	**Training time**	**Sufficient training time?**
1	No	Yes
2	No	Yes
3	No	No
4	15 min	Yes
5	No	Yes

Table 2.4 Training time

2.5.4 Ability to complete the task

All the pupils were able to complete their tasks within the school hours intended, except pupil 2, for whom the map learning was rushed in the end in order for the pupil to feel that a task was well accomplished.

Participating person	**1. How well do you rate your/the pupils task solution?**	**2. Compared to normal material, how well did the app. help you/the pupil to solve the task?**	**3. Compared to normal material how well do you think your/the pupils' result was?**
Pupil 1	4	5	4
Teacher assistant 1	4,5	4,5	3
Pupil 2	4	5	5
Teacher assistant 2	4	4,5	4
Pupil 3	3	2	2
Collaborator 3	4	4	4
Teacher assistant 3	4	4	4
Pupil 4	4	5	3,5
Collaborator 4	4	5	5
Average	**4,3**	**3,8**	**4,1**

Table 2.5 Table of individual ratings and averages for questions of satisfaction of system.

After the test, the pupils 1-4 and their teacher were asked about their opinion regarding their own performance using the system, compared to the usual way to do the same task. There were 3 questions assessing the task performance, and they are summarized below in a table, but also with the average rating of the pupils and the teachers together. The pilot test with pupil 5 did not have the same post-test interview questions.

2.5.6 Evaluation issues of co-operation – KTH collaboration test

Collaboration

The collaboration was in a way parallel due to the formulation of the task but it was done in a shared interface. The sighted pupils were not allowed to see the drawing action of the visually impaired pupils and the visually impaired pupils were not allowed to feel when the sighted pupils drew a picture. In one case one of the visually impaired pupils reached over with the Phantom pen into the sighted pupil's part of the drawing surface in order to follow the peer's drawing but was told not to do so. This might suggest that it would be useful for the visually impaired pupil to follow the sighted pupil's drawing when it is actually done in order to support awareness of what is going on in real time instead of getting a description afterwards. This would probably also support verbal guiding that we have seen is useful in earlier studies.

The pupils in the pairs understood the task in itself without any problems. However, the visually impaired pupil repeatedly said things like "yours is much better" to the sighted pupil, "mine is not at all as nice". It is probably the case that drawing is something that is generally quite hard for a visually impaired pupil to do and is something that they have little experience of, and that they do not feel very confident in doing. This said, all pupils did manage to produce drawings that they could discuss together and certainly the visually impaired pupils could with varying success experience and explore drawings together with a sighted peer.

Shared understanding of the workspace

The understanding of the layout of the environment appeared to be shared by the pupils in both pairs. They did not cross the line, which divided the drawing surface into two separate once, except when they did it on purpose. This shows that they had a common understanding of the line and that they had one area each to draw upon.

Both the visually impaired pupils and the sighted pupils could efficiently use concepts such as triangle, circle, square and rectangle. Also, in one pair the pupils drew a human and they had a common understanding of the symbolic way of drawing a human with a head and lines for the body, legs and arms as the following dialogue shows:

Visually impaired	- okay, now I am ready (has drawn a lineman)
Visually impaired	- it is a lineman, and there is first a triangle.
Sighted	- okay, and then a line right?
Visually impaired	- yes, and then two legs well you know what a lineman looks like.
Sighted	- two arms?
Visually impaired	- what?
Sighted	- two arms?
Visually impaired	- yes
Sighted	- okay, I'm done.

The pairs also successfully used referencing such as, on the top and the bottom of the paper, above, below and so on. The following example shows referencing:

Sighted	- on the top close to the edge there is a triangle.
Visually impaired	- on the top?
Sighted	- aha, with the point up.
Visually impaired	- aha.
Sighted	- then a little further down, but not stuck together, there is a square
Visually impaired	- aha, and what’s next?
Sighted	- then at the bottom I have a circle.
Visually impaired	- mm, aha, I am done.

However, it is unclear to what extent the totally blind pupil really understood the shape of the drawings if they tried to explore them with the Phantom pen as the following example indicates:

Sighted	- up here is the square and there is the circle that you are at now (the sighted person says what it is that the blind pupil investigates).
Visually impaired	- aha
Sighted	- and that is the square.
Visually impaired	- aha
Sighted	- that is the dividing line.
Visually impaired	- aha
Sighted	- that is the circle.
Visually impaired	- did you mean over here?
Sighted	- that is the circle.
Visually impaired	- aha, eeh, I don’t understand (puts down the pen but takes it up again) this is the worst…
Sighted	- that is the square.
Visually impaired	- aha
Sighted	- that is the circle.
Visually impaired	- aha, but okay (puts down the pen).

It appears as if it works rather well for the visually impaired pupils to draw a standardized shape, because she/he has some knowledge about that kind of shapes. It is also relatively easy to find the different shapes at the work surface, but it is harder to feel the form of the shapes by exploring them with the Phantom pen if the peer in before hand does not name them.

Interview results

Both visually impaired pupils commented that it was frustrating that there were no borders around the drawing surface, which made it easy to slip behind it. They were also irritated that they could accidentally push through the drawing surface, which made them lost in the space behind the drawing surface.

The totally blind pupil said that she did not like the system. She thought that it was hard to feel and have control over what she was drawing. She would have preferred to feel the line that she was drawing with the right hand with her left hand in order to get feedback on how well it was drawn. Today, when she is drawing with plastic paper in school she uses both hands:

Visually impaired	-I have the pen in one hand, and then I feel with the other …in that way I feel if it is crocked immediately but with that thing (haptic pen), when you have to go back and release that button and so on, then you do not find your way back, it is much harder I think.

Furthermore, she felt that it was very hard to feel the shape that her peer had drawn (with the computer mouse) with the haptic pen. For her drawing was not so interesting at all, she preferred to explain things verbally. But she did think that the system might have some use for her if she could show things for others more easily. The visually impaired pupils in both groups thought that it went better the second time they did the task.

One of the visually impaired pupils said that he thought that it was easier to draw horizontal and vertical straight lines, but that it was harder to draw diagonal straight lines as well as curves. This pupil suggested that it would have been easier if he got more help from the system so that loose ends for example were connected into perfect shapes. He also said that it would have been good with a menu with a few standard shapes such as triangle, circle, square and rectangle that he could chose and that he could also decide the size by clicking a certain number of times on a shape.

The totally blind pupil said that the haptic feedback made it possible for her to find the shapes that had been drawn but that it was hard to recognize the shapes by exploring them as the following example shows:

Interviewer	- could you feel the drawings?
Visually impaired	- yes, but I did not feel very well what it was, because that was hard, but I felt if there was something there or not.

Both the visually impaired pupils reported that the audio feedback was to fast and that it was hard to understand what was said. The audio information was however of some use for noticing the dividing line in the drawing surface even if it apparently would have been enough with the haptic feedback.

Both the visually impaired pupils reported that they did not think that they and their peers had the same view of the layout of the workspace and the drawings. They did however think that they managed to discuss the drawings in general even if they thought that they probably had quite different views of it. The following example illustrates this:

Interviewer	-do you think that you had approximately the same understanding of the drawing or not?
Visually impaired	- if you could see then you would have the same understanding but when you just feel with this you probably do not have the same understanding because it is easier to see exactly what you do than with this thing (haptic pen).
Interviewer	- what is the difference?

Visually impaired	- we perceived it in a similar way but it is harder to catch the details

The other pupil said the following that illustrates the same thing:

Interviewer	-do you think that you had approximately the same understanding of the drawing or not?
Visually impaired	- I don’t know, no maybe not.
Interviewer	- do you think that you could discuss the drawings?
Visually impaired	- yes.

The pupil with some sight left thought that he would have liked to have a computer screen as a complement to the haptic feedback.

In both groups the visually impaired pupils liked the guiding function a lot and would have wanted to use I more. The totally blind pupil said the following that illustrates this:

Interviewer	- what did you thing about the guiding?
Visually impaired	- that was very good I think, yes that was rather good because it is easier then because it is faster, and then you can see it and then one knows directly how the line goes, then you do not need to search for it and then it is easier.

They both did however say that it was a bit too fast and that it could pull the pen out of your hand that this example shows:

Interviewer	-was there any problems with the guiding?
Visually impaired	-yes, it was a little too fast and jerky.
Interviewer	- what happened then?
Visually impaired	-you lost it

One of the visually impaired pupils suggested that this system could be good in for example the Swedish class because then others could guide him to certain places in the text.

2.6 Discussion and conclusions

Getting access to 2D graphics is still a large problem for users that are severely visually impaired. Using a haptic display in combination with audio feedback is one way to enable access. General guidelines to create and develop haptic applications and models are collected in [4]. Applications making practical use of non-spoken audio and force-feedback haptics for visually impaired people are e.g. applications supporting mathematical display [5], [6] & [7], games [8-10] and audio-haptic maps [8;11]. As described in [12] and [13], there are indeed people who are blind who have an interest in hand drawing. In [14], a CAD application is presented that enables users to create drawings with the help of audio and keyboard. In [15], a study on a haptic drawing and painting program is presented.

We have done some usability studies during the development of the drawing program [16] and we also did a final test in the schools [17;18]. The technology is still not mature, and the fact that we have been able to test an application in real use situations (real tasks in real classes at school) is a step towards getting this type of technology to the end users. In general the results of our test show that programs like the AHEAD application could be a useful complement to the materials already used by visually impaired children at school, which has also been suggested in [19]. Despite the single point haptic interaction provided by the PHANToM, pupils found that the AHEAD application provided good access to the displayed 2D graphics, and two pupils in particular commented that this was actually better than the raised line images (despite the fact that these can be explored by all fingers simultaneously).

The fact that the environment allowed for both a mouse user and a PHANToM user to have access to a common workspace was seen to be important, and to increase the usefulness of the application. The guiding function where the mouse user guided the PHANToM worked well when the mouse user used a guiding motion to lead the PHANToM user to a target or show a shape. The result of the guiding depended on how the mouse user used it – and the test results indicate that one should advice the mouse user on how to use the guiding efficiently. Still, it is important to note that some users may not like being guided (these results agree with the observations made in collaborative haptic environments with multiple PHANToMs [20]).

It is interesting to note that the visually impaired test users at KTH had problems both with falling through the surface and the absence of haptic limitations to the workspace. We interpret the fall through as being due to limited processing capacity, while the need for haptic limitations is an old guideline [4] which we did not include in the design since it made the available drawing area much smaller. Also, the ULUND tests indicate that more experienced users do not seem to have problems with this. Our interpretation of these results is that the haptic limitations are important for new users, while experienced users are able to make it without them.

From the KTH study we see that the visually impaired pupils felt that it was possible to talk about the drawings, and that they could do the task, even if they did not think that they had exactly the same understanding of the environment as their sighted peers. It should also be noted that in the KTH study the blind pupil reported more problems, while in the ULUND study the blind pupils did well – this indicates that there are many background factors that affects the results, training not the least.

Finally, the usability problems observed suggests that a Braille display should be connected to the system and that the user should be able to change the orientation of the virtual paper. A zooming function to access small details could also be useful.

3. Solar system

3.1 Executive summary

The usability and usefulness of the Solar System application has been evaluated in a collaborative learning situation. Four pairs of visually impaired and sighted children used the Solar System application at their schools and the analysis has been focused on the usability of the new parts of the application and their usefulness for collaboration. The overall results of evaluation concerning the guiding with the mouse and the note-making function were promising, though some usability drawbacks were still found. Children liked to make their own notes on the system and particularly liked the possibility to listen to their own writings. The small buttons of the Magellan device used for the notes taking part were a bit difficult to find correctly by the visually impaired but the navigating in system succeeded quite well. The stability of the system was also good.

3.2 Background and objective

The Multimodal Interaction Research Group of Tampere Unit of Computer-Human Interaction has during several years investigated multimodal interaction models for visually impaired children. Researchers have implemented user interfaces for different haptic devices, for example steering wheel with force feedback and the Phantom device. Usability tests have been conducted investigating the benefits of haptic feedback in different situations [21;22]. In the Proagents project, which was a part of the Proactive Computing Research Program (funded by the Academy of Finland) in 2002-2005, a multimodal learning environment was designed for visually impaired children. This Space application was designed to support children's exploratory learning among astronomical phenomena[23]. Investigations of the Space application and also the other previous studies have concerned single user situations. In the MICOLE project the focus has been on collaboration and especially the collaboration of visually impaired and sighted children. In this project the Space application has been investigated in collaborative settings (in MICOLE deliverables D9 and D10) and according to the results of those studies it has been further developed to support collaboration.

3.3 Application

The Solar system is a learning environment for visually impaired pupils for exploring the objects of our Solar System. It is a part of a Space application we have evaluated earlier and it is designed to be used together with sighted children in a collaborative situation. The application uses two screens for display: The Solar system view in one and the Notebook view in another one (Fig. 3.1). In the Solar System screen the user can explore the orbits of the planets with the Phantom stylus and the speech synthesizer tells which planet's orbit is in question. When finding a planet the user can go to explore its surface by pushing the planet with the stylus. Also the Sun can be explored. On the surface of the object it is possible to feel the shapes and textures of it and listen to some extra information by pushing a little button on the stylus.

The other screen shows a notebook view consisting of three fields and the title according to the context. In uppermost field all the previous notes written in a certain context can be seen. The other two fields are for writing a note: a title field and a content field. The notes are manipulated by a Magellan space mouse. Ordinary keyboard is in use for typing but other functions like activating the field, listening to the note, moving to the next note and saving a note are made by pressing the small buttons of the Magellan input device.

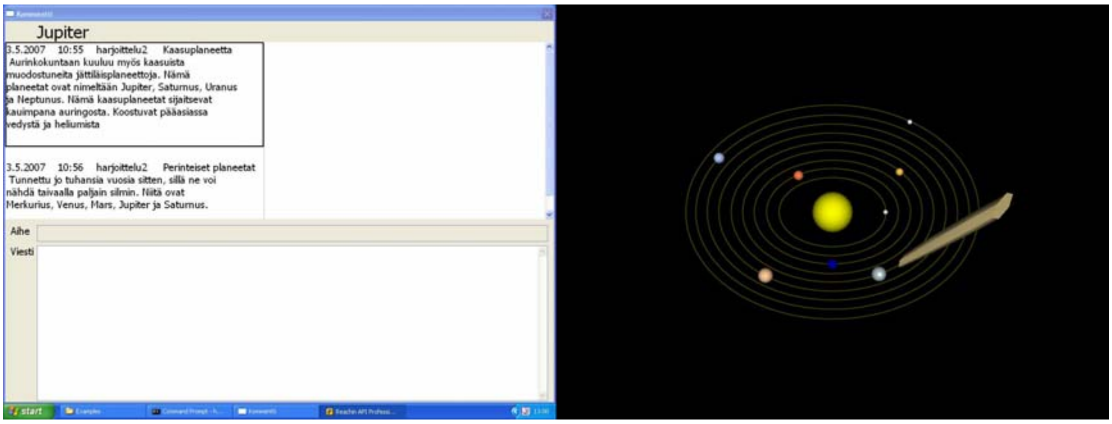

Figure 3.1 Two screens of the application

3.4 Evaluation

The aim of this study is to evaluate the usability and usefulness of the Space application in a collaborative learning situation. Four pairs of visually impaired and sighted children used the application at their schools and all the sessions were videotaped. The analysis has been made partly according to the procedure of the analysis on the previous collaborative study described in deliverables D9 and D10. As the application has changed and new collaborative tools have been designed, the evaluation has been focused on the usability of those new parts.


Figure 3.2. Two children (one sighted and one visually impaired) are exploring the surface of a planet.

3.4.1 Participants

Four visually impaired and four sighted pupils participated in testing, which took place in three schools. Age of the children ranged between 7 and 9 years. One of the visually impaired children was blind; other three could utilize their sight a little. Furthermore, one visually impaired and his sighted partner had a hearing defect. They still could hear a clear speech and beforehand this impairment was thought not to cause problems in testing. During the test it was realized that the hearing defect has an effect on children's conceptual understanding and thus the testing had to be tailored for them.

	Pair 1		Pair 2		Pair 3		Pair 4	
Sight	Blind	Normal	VI	Normal	VI	Normal	VI	Normal
Age	8	9	8	8	7	8	8	8
Gender	F	F	M	F	M	M	F	M
Relationship	Schoolmates		Schoolmates		Schoolmates		Schoolmates	
Other disability					hearing defect	hearing defect		
Previous experience of Phantom device	Yes	No	No	No	No	No	No	No
Computer use	weekly	occasionally	occasionally	weekly	Almost weekly	occasionally	occasionally	weekly

Table 3.1. The background information of the participants in ordinary tests. (In analysis pair number 3 has been partly left off because of the different testing procedure.)

3.4.2 Context

Three of the tests were done in normal schools where visually impaired pupils were integrated in class with sighted pupils. One of the schools was a special school for hearing-impaired pupils.

Testing was done in the beginning of May 2007 during the ordinary school days but in separated rooms. Only the testing pair was present and three researchers (one for technical support, one observing and one working with the children). After the test we invited also the rest of the class to try out the application.

Our test set-up consisted of one computer with a keyboard and a mouse, the Phantom Desktop device, Magellan space mouse, two 17" LCD monitors and stereo loudspeakers. As we were not testing in a usability laboratory, we needed also portable devices for video recording: a digital video camera, DVD recorder, mixer and two microphones. For introducing the application we used a plastic model of its solar system view and a plastic stylus like that of the Phantom device. Children get thus more familiar with the haptic environment they met exploring the application. This is important especially for the visually impaired children who can't utilize the visual feedback.

3.4.3 Procedure and tasks

We have collaborated with a teacher of geography when designing the test tasks and she was also observing the first pilot test and gave us a lot of valuable feedback for the main tests. This teacher was not working in any of the schools where we conducted the tests but she has previous experience in teaching with a visually impaired person integrated in her geography class.

A pilot test with two sighted children (9 and 12 years) was conducted to investigate both the stability and the usability of the application and the adequacy of our testing procedure. As the procedure proved to be too time-consuming, we organized another pilot test (two sighted children of ages 7 and 8) in which the amount of the tasks was reduced and also the training section was shortened. The final tests took about 1 hour and 15 minutes each, including the interviews, training and the testing itself.

The procedure started with a warm-up interview after which the assistant discussed with the children about solar system, the content area of the application. Then they were taught to use it by means of the real world model and the plastic stick. Both children were taught also to hold the Phantom stylus properly and to operate with that device. We used first a training version of the application by which all the functionalities of the application were taught to the children. They were guided to the planet Pluto for learning to make notes and listen to them, to navigate between the solar system view and the individual objects and to listen to the additional information about them. Also the guiding with the mouse -function was shown to the children. In the beginning of the test the children were allowed to explore the application freely for a couple of minutes and after that they were asked to complete four tasks given by the assistant one by one. Tasks were read out and given also written to the children.

The tasks were the following:

1) Locate Finland on the globe.
2) How long does it take a shaft of sunlight to reach the surface of the Earth after its departure from the surface of the Sun?
3) Two stone planets of our solar system have no moons. Which are they?
4) Why is it impossible for people to live on the other planets? Examine three planets of your choice and write down at least one reason for every planet as an answer.

Before the fourth task the children were discussed the prerequisites of life, how is it possible to live on the Earth?

The answers were to be written in the notes section of the application. The children were advised to use the application together and also to think aloud. They could be helped in making up the titles for their own notes. That proved to be quite difficult for the children at this age according to the pilot tests.

3.4.4 Interviews

In the beginning of the testing situation the children were asked some warm-up questions according to the preliminary questionnaire that was answered by their parents. They were asked about their computer use, previous experience in haptic devices and about group work or pair work at school.

After the use of the application and completion of the test tasks the children were interviewed together. The following questions were asked starting by turns with the sighted and visually impaired partner:

About use of the application

1. How did you like to use the device?
2. What was nice in the application?
3. Was there anything you didn’t like? If, then what was that?
4. Was there anything that specially stuck in your mind? (ask about different modalities)
5. Was there anything you didn’t understand? If, then what and how?
6. What did you like about the tasks?

7. What did you want to know more about?

About collaboration

8. How well did you manage to do the tasks together?
9. What was best in working together? Why?
10. What was most troublesome in working together? Why?
11. What good points do you see in having this kind of application at school?
12. What good points do you see in using traditional books and note books?
13. What feature/s of the application did help you in doing group work?
14. Was there anything that makes it difficult to work together using this application?
15. What improvements does the application need to be more useful for group work?

3.4.5 Methodology

Targets of the analysis were completing the given tasks (usability and collaboration issues) and the interviews of the children (usability and collaboration issues).The analysis was made according to the video recorded observations. Usability related observations were classified according to their context, e.g. “buttons”, “notes”, “Phantom” and “guiding with mouse”. Issues concerning collaborating (dividing of the roles, activity, solving the tasks and commitment) were evaluated by two researchers and the results were collected together. The number of observed actions of the children and their verbal and non-verbal expressions were collected to the table as well.

3.5 Results

3.5.1 General usability

All pairs of children managed to use the application and all except one pair finished all the tasks. The children of that pair had both a hearing impairment too, which caused problems while doing the test. Our application set-up consists of many devices and one of the main challenges was how to place them without disturbing the users. For the visually impaired children who could utilize the visual feedback we had to move the screen so near that there was no space enough for the Phantom in front of the user. Thus the Phantom had to be placed beside the screen which caused ergonomic drawback for the Phantom user. Also in situation where another child was left-handed it was difficult for her to help with the Phantom.

In our previous tests the stability of the system caused trouble but now the application didn’t crash at all during the tests. That is important as the crashing always breaks a collaborative activity. A few problems still occurred in the Solar System view while exploring with the stylus in peripheral areas of the haptic field: the stylus shook and made children comment like “hey, what’s that, what’s happening?” In one case the sighted child guided the Phantom user away from the shaking edge with the mouse.

Usability of the notes

The possibility to make own notes was a successful feature and all the children in pilot tests as well as in the main tests liked to hear their own comments read by the synthesizer. Some usability problems anyways were found in using the notes.

The context information (e.g. name of the object in hand) can't be heard from the notes. Only the sighted child can thus check from the notes screen where they are exploring at a certain moment. Sometimes it happened that not either the sighted child utilized this possibility but asked the visually impaired "where did you go?" It is possible that the use of two screens is a bit strange and they didn't remember to use it.

The buttons were a bit cumbersome. Four buttons were needed to use the notes: one for choosing the cursor, one for moving to the next topic, one for listening to the note and one for saving the note. The buttons of the Magellan space mouse are so small, that it was bit hard to mark them properly for the visually impaired. We made some kind of signs using sand paper but they didn't stick well enough and the children had to remember them. As the finding of the right button was a bit slow for the visually impaired child the sighted child often made it first. This was inconvenient for the child with visual impairment who was already trying to push the button.

The edit-button was most difficult to remember: with that button the cursor was placed either to the text or the topic area. The children forgot to check the cursor position and that's why they started to write in the wrong place. Sometimes they tried to move the cursor with mouse and sometimes using a keyboard. Both are common ways when using an editing program like Microsoft Word or Notepad but in Space application they were not in use. Some visually impaired can use the keyboard and in our tests one of them used it some time. When they were writing they couldn't see the cursor and that was one reason for writing in wrong place.

One challenge in writing notes was the division of work in collaborative setting. When one child was writing a note and the other one happened to push a button for saving the text the unfinished text disappeared from the text field. There were two issues related to that phenomenon: First, the saving function didn't give any feedback by sound or haptics. The saved text just disappeared and came visible in the list of notes. So the visually impaired child didn't realize that the text had been saved. Another drawback was that the text couldn't be continued after saving it.

Guiding with the mouse

A new feature in the application was the guiding with the mouse. The sighted child could help the visually impaired child to find a certain target by dragging the Phantom stylus using the computer mouse. This possibility was greeted with satisfaction. They intended to use it several times, although the verbal guidance outdid in number of occurrences as a more common way to help each other (see Table 3.3).

One drawback with this guiding feature was that the Phantom moved too fast and with too much force. It happened that the Phantom user couldn't hold the stylus when it started to move towards mouse cursor. The stylus fell down or the child at least got frightened when it suddenly moved by itself. When we realized this we asked the children to tell the partner when they planned to guide him/her.

The cursor of the mouse was a red cross which wasn't visible enough when watching the video recordings. But the sighted children could see it well and it happened that one sighted girl used only the red cross cursor to guide the other child. She didn't push the left mouse button but just asked the other to move towards the red cross. In this pair the visually impaired child could use the visual feedback too but the cursor was still quite invisible for him. Sometimes the cursor also disappeared from the screen.

Especially in the first test task where the children were asked to find Finland on the globe, it was observed that strict points are difficult to locate even when guided with the mouse. Additional investigations are still needed to solve if this is a cause of Phantom or the mouse or maybe both of them.

3.5.2 Exploration and navigation

The navigation between solar system and the surfaces of the planets went well. One child tried to go back to the solar system view by pushing the stylus again, like when moving from solar system to the surface of the planet. This aroused a notion that maybe it would be intuitive to use the same manner to navigate in and out of the scene. Anyways the big button of the Magellan space mouse was well remembered for navigating back to the solar system. This button also worked properly in these tests, only once it happened that a child needed to push it twice.

The exploring between the orbits of the planets in Solar System was a bit challenging as the orbits were so close to each other. It happened that the stylus prompted over the next orbit and the user couldn't follow the orbits in order. This can have an impact on getting the overview of the content. The orbits of the planets and the planets themselves are introduced like "you are now on the orbit of the Mars" but when the sun is touched the voice tells that "you are now just by the sun". This made one visually impaired wonder how to get into the sun as you now were only beside it.

3.5.3 Assistance

Assistance by the test assistant was divided in ten different types that we observed from the videos. Those types and occurrences of each are presented in Table 3.2.

Assistant's aid	Task 1			Task 2			Task 3			Task 4		
	visually impaired	both	sighted	visually impaired	both	sighted	visually impaired	both	sighted	visually impaired	both	sighted
Solar System, verbal guiding	3	4	2	2	1	1	7	1	5		2	
notes, verbal guiding				3	4	4	2	7	1	2	1	
verbal instruction in spelling					4	5		16	5		2	13
guiding with mouse				1					1			
using the stylus (assistant alone)	1	1										
using the stylus (with the child)	3	1					2		1			
pointing						2		1				
motivating		4		2	11			26	1		12	2
reminding of the task		1	1		1	1		5				1
asking the answer			1	2	3	2		2	1			

Table 3.2. Occurrences of different types of assistance. Division is made according to the target group of the assistance: the visually impaired, the sighted or both together.

The children assisted also each others and this reciprocal helping will be discussed in Chapter 3.5.6 Evaluation issues of co-operation. All the pairs needed help in some tasks and the most common type of assisting was motivating. As our approach was more like a lesson than a test situation this is maybe quite obvious. Almost half (47%) of the occurrences of motivating took place in task 3: “Two stone planets of our solar system have no moons. Which are they? “. In this task the cue could be found in notes which were written beforehand by test organizers. In every stone planet there was a note which told the names of all the other stone planets too. Thus the children didn’t have to explore all the planets but only those four (or three, because Earth and its one moon should be familiar to them). This proved anyways too challenging for the children and they needed a lot of guiding discussion with the test assistant.

3.5.4 Ability to complete the task

All of the pairs except the one having also the hearing defect could complete all the tasks. The hearing-impaired children proved to have a lot of difficulties in understanding concepts and thus the test had to be tailored to their abilities. For example in the start-up interview they didn’t understand what co-operating means, though the test assistant tried to put it with different and very easy and simple words. Discussion with their teacher confirmed this observation: when a child is hearing impaired from the birth or has got the hearing defect in the very first years of the childhood, this has an impact on development of the understanding of concepts.

Although the children managed to do the tasks their abilities to use keyboard and to spell the words correctly were still in quite low level. The application included also a lot of difficult words that were not familiar to the children (like some of the names of the planets). That’s why it took a lot of time to complete the tasks in which they were to write the answers on the notes.

3.5.5 Evaluation issues of co-operation

In our previous tests (described in MICOLE deliverables D9 and D10) we found that the child using the Phantom device seemed to dominate a bit in collaboration. Now there were more interaction possibilities in the application and it seems that using the keyboard in writing the notes dominates as well as exploring with the Phantom. When one partner was using the Phantom the other one didn’t have much to do and when the other one was writing the note the Phantom user for one got a bit bored. During the sections when one child was actively operating the stylus or writing a note they still could collaborate verbally.

Guidance

Observations on children’s reciprocal helping have been collected in Table 3.3. There can be seen predictably that all the guidance happened by sighted partners. Most of all they guided by telling the other one in which direction to move or where some object could be found. In first task they also pointed to objects quite often, which is common way to guide a sighted person but not very effective for guiding a visually impaired person. Some of the visually impaired children could anyways utilize the visual feedback so that once this type of guiding even succeeded. When test situation proceeded the pointing phenomenon disappeared, which can be interpreted as adaptation to the situation by the sighted child. None of the sighted children in our tests had previous experience in doing pair work just with visually impaired child thought they were classmates.

The guiding with mouse was a welcome utility and children seem to like using it. In one case the child even guided himself holding the Phantom Stylus in one hand and moving it with a mouse in another one! Children also sometimes used the guiding function to tease each other. The usability problems (discussed in Chapter 3.5.1

General usability) decreased a little the usefulness of this function as can be seen in Table 3.3: In first task only one out of four guiding trials succeeded, in third task neither of them and only in second task the sighted child could guide the visually impaired one to the right place.

Children's reciprocal helping	Task 1		Task 2		Task 3		Task 4	
	Visually impaired	Sighted	Visually impaired	Sighted	Visually impaired	Sighted	Visually impaired	Sighted
speech (in brackets when succeeded)		11		2 <1>		<2>		1
mouse (in brackets when succeeded)		3 <1>		<1>		2		
stylus (in brackets when succeeded)		3 <1>		<1>				<2>
pointing/showing		9		1 <1>				
writing						1		
total		**28**		**7**		**5**		**3**

Table 3.3. Occurrences of helping between children.

Common ground and awareness

The children managed to complete the tasks well together and the discussion about the task at hand helped them through the tasks. The structure of the application (two screens, one for editing notes and another for exploring the solar system) might have an influence on the work flow: the children took turns in doing actions and sometimes this caused a break in collaboration. For example, when sighted child was editing the notes the visually impaired didn't in every moment know what was going on and it happened that he or she saved the note before it was finished.

In the Solar System application there are different feedback channels for the users to be aware of another user's situation. They can utilize the visual feedback like the color of the Phantom cursor (the sighted children) and the sound feedback telling about the planets and their orbits (the visually impaired and the sighted ones). The actions of the children happen more in parallel than simultaneously. Only the guiding with the mouse occurs always simultaneously and the notes can be written both simultaneously or in parallel with the exploring. So the awareness of the situation of the partner doesn't have as big influence on completing the tasks together as in the applications where the tasks have to be done more simultaneous.

As the children collaborated quite well by discussing about what was happening, the occasional lack of awareness or common ground on the other hand could bring along active collaboration. If the children had been working all the time simultaneously, they possible had missed some fruitful discussions.

3.6 Discussion and conclusions

The Solar System application has been tested in a collaborative learning situation between visually impaired and sighted children. All except one of the four pairs completed all the test tasks together. This one pair that couldn't finish the tasks has also hearing defects. Hearing impairment can have an effect on the rate of basic concept development of children. The basic concepts can remain delayed for deaf children unless they were specifically taught to them [24]. In our testing the problems seemed to be just in the conceptual level concerning the target-oriented learning, in which the tasks were defined by researchers. When the hearing impaired children used the application freely they were enthusiastic about the possibility to feel the surfaces and to write down their observations. They collaborated and changed the roles too. This finding also reminded the sense of inner motivation in learning. When children will be allowed to set their goals and questions themselves they could be more likely to finish the tasks and work more excited to attain the target.

The application set-up with two monitors, keyboard, Phantom device, stereo loudspeakers and the computer mouse needs a lot of space on the table. It is thus a challenge to place them ergonomically for the children with different characteristics. One possibility to facilitate the circumstance could be locating an additional little and shallower work surface for the Phantom between the children. The set-up should be customized for every pair of users, taking care of for example left or right-handedness.

The note-making possibility was accepted well and this tool is worth developing further. For example the possibilities to not only write but also to record one's own notes and then listen to them would be useful. This could help of course the visually impaired but also the sighted child with lower typing skills. One of the most serious usability problems was the ability not to continue already saved notes. If the child didn't tell the other his or her intention to save a note, the note could remain unfinished when saved. So the application should allow users to continue editing the saved text as many times as they prefer.

Guiding with mouse was a new feature in the application and children used it a couple of times. This mode of guiding seemed to be natural for the children and it's thus worth further developing. The force and speed of the Phantom guiding needs to be adjusted to better follow the movements so that the stylus is possible to hold. The cursor of the mouse should be visible enough for those visually impaired children who can utilize the visual feedback too. Additional investigations are also needed to solve if the difficulty to find strict points is a cause of Phantom or the mouse or maybe both of them. In addition the cursor has to be restricted to the visual area only, so that it will not confuse the users.

The basic navigation between the solar system view and the individual planets went well: pushing the stylus towards a planet to select it and pressing the big button of the Magellan device to return to the overview of to the solar system. Once it happened that a child tried to get back from the planet's surface by pushing the stylus again. This is a common way to use the on/off switches in every day devices e.g. radios and CD-players. But in Solar System application this kind of use could present a problem when a child is exploring the surface using rather a lot power and moving accidentally back to the solar system view. The moving from one orbit to another one in solar system view was a bit cumbersome. The orbits are situated quite close to each other and some unintended jumps occurred. This could have an influence on getting a general view of the environment. The visual view is all the time available for the sighted child when the Solar system scene is chosen but for the visually impaired the general view should be offered also as easy as possible with the haptic feedback.

Children found the contents of the application interesting and only one child pointed out that some extra information could have be offered about Pluto, Mars and the sun. It seemed anyway that this pair didn't visit those objects in test situation. On the other hand the amount and especially the quality of the information should be planned out to fit the target group. Some concepts and words in Solar system application were strange to the children and this could have an influence on completing the tasks and assistance needed in writing the notes. It is also very important to design all the sounds and speeches carefully because children may think very concrete and straightforwardly.

4. Electric Circuits

METZ

4.1 Executive summary

The usability of the Electric Circuits exploration software has been tested with 13 visually impaired children from several schools and centers around Metz. The 4 children of the St. Eucaire elementary school (Metz) did the tests at their school, during the lectures times. 2 pupils from Schuman secondary school and high school (Metz) did the experiments at the school, but during free time in their schedule. The users are currently in high school but were in secondary school at the beginning of the project. Finally, 7 users from Santifontaine Center (Nancy) did their tests at home on holidays or weekends except three users that did the tests at the center.

Although the tests were designed to stimulate collaboration between the child and the teacher, the children preferred to try to complete the task by themselves as they took these experiments as exercises. Half of the users used tactile cues on the VTPlayer to identify the components, and the other half used the force feedback cues with the PHANToM.

4.2 Background and objective

The Electric Circuit exploration software allows exploring electrical schematics with a PHANToM and a VTPlayer. The interesting feature in this application is the multi-level exploration: global for the schematic shape recognition and local for components identification.

4.3 Application

The user is constrained to an electric circuit schematic. He can try to recognize the circuit shape by navigating in the circuit like in a maze. The components can be felt in two ways. The first one is to feel the bumps on the lines: half-guided PICOB interaction [25]. The other way is to use the VTPlayer patterns. Each component has a 4x4 tactile pattern associated. So the user has to choose which information he wants to use to understand the components.

Some guidance systems have been implemented. Three guidance modes with the PHANToM have been implemented. The first one is a playback system: the user can record the path he is doing. Then he can replay it anytime so that he can feel another time the path he followed. The second one is guidance by a mouse. In this case one user explores the circuit with a regular mouse, and another user is dragged to the mouse position. The third guidance system is used when the user cannot find his way. In that case he can press a button to be dragged in the directions he can go. It is mainly useful at the junctions. This interaction is the guided-PICOB interaction [26].

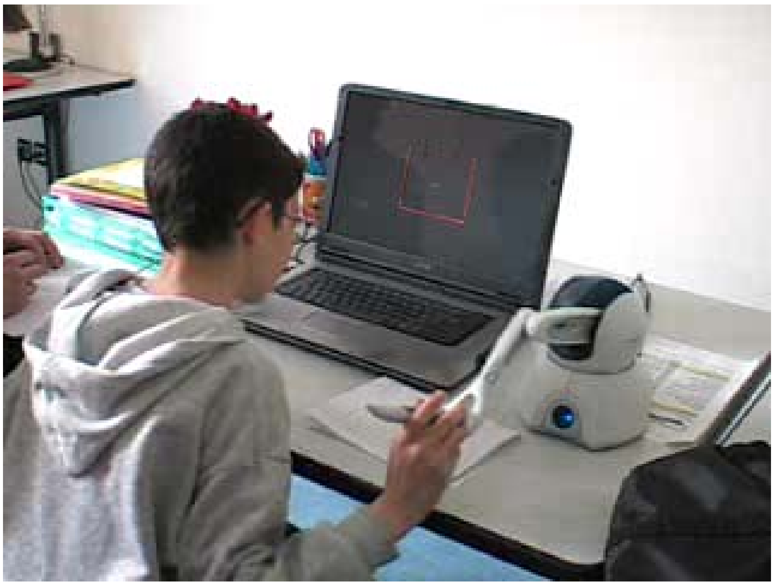

Fig. 4.1 A child using the system

The VTPlayer is used for guidance too. We use tactile icons [27] to give directional information. We use them when the user asks for help, in addition to the guided-PICOB.

4.4 Evaluation

The software is meant to be use alone, or with the help of a teacher. The users had to use the software in both conditions in order to show the impact of the collaboration aspect.

User	Age	Vision	Haptics knowledge
1	11	0.05 / 0.2	PHANToM, VTPlayer, vibrating joypad, force feedback joystick
2	11	?	PHANToM, VTPlayer, vibrating joypad, force feedback joystick
3	9	5	vibrating joypad
4	11	2	PHANToM, VTPlayer
5	17	Blind from birth	PHANToM, braille keyboard, reads and writes braille
6	17	0.5 / 0.1 (didn't use vision)	PHANToM, VTPlayer, reads braille
7	14	1 / 4.5	vibrating joypad, force feedback joystick
8	16	1.4 / 2.4	vibrating joypad
9	13	0.05	vibrating joypad, force feedback joystick
10	15	0 / 0.1	vibrating joypad
11	16	2 / 0.5	vibrating joypad, force feedback joystick
12	17	Blind from birth	reads braille, raised paper, Perkins machine
13	around 17	Blind	reads braille, raised paper, Perkins machine, vibrating joypad, force feedback joystick

4.4.1 Participants

13 visually impaired participants aged from 9 to 17 years took part of our experiments. 10 have partial vision, and 3 are blind. 2 of the 3 blind users are blind from birth. 2 of the blind users have a mental deficiency in addition to their vision problems (users 12 and 13 in table x)

Some of the users already knew the PHANToM and the VTPlayer as they participated in previous tests and have briefly tested older versions of the program (users 1, 2, 4, 5 and 6). Some users already used haptic devices for video games: vibrating joypad (users 1, 2, 3, 7, 8, 9, 10, 11 and 13), force feedback joysticks and wheels (users 1, 2, 7, 9, 11 and 13).

4.4.2 Context

The users come from 3 institutions:

- St Eucaire primary school (4 users: 1, 2, 3 and 4)
- Robert Schumann secondary school (2 users: 5 and 6)
- Santifontaine center (7 users: 7 to 13)

The tests with the users of the first two places have been conducted at the school. The users of the third place are not permanently in the center. So we did the tests there for 3 users, and for the 4 others, we did the tests at their home. So every user except the 3 users who did the tests in Santifontaine is integrated in classes with sighted users. The tests at the schools and Santifontaine have been conducted at school time. The other users did the tests on Saturday, Wednesday afternoon, and holy days.

Users below 12 years old have very poor knowledge about electric circuits. Users up to 16 have basic knowledge: they know what a lamp, a battery and a resistor is. The others know quite well the electric circuits, except the last two users (12 and 13) because they have mental deficiency and can be classified in the second category.

4.4.3 Procedure and tasks

The users begin with filling the pre-questionnaire. The experimenter explains him the experiment purpose. The experimenter plays the role of a teacher during the experiment. The same experimenter has been chosen for all the tests.

The tests begin with an exploration of the devices (PHANToM and VTPlayer) by the children. The experimenter explains him the purpose of the devices, and how to use them. Then the experimenter runs some demos to make the user the devices behaviour. The software used for the VTPlayer is a demo showing the directional icons. The software for the PHANToM is the Dice demo from Sensable, and the Reachin demos.

Then the user is presented his first electric circuit (figure 4.3) in order to show him how to explore a circuit, and to show him how the components are represented (both for VTPlayer and PHANToM). In this experiment, we restrict the components to the Resistor (3 bumps on the PHANToM, square pattern on the VTPlayer), the Battery (2 bumps on the PHANToM, one small and one big line pattern on the VTPlayer), and the Lamp (1 bump on the PHANToM, cross pattern on the VTPlayer). The user is given a description of the codes and patterns (number of bumps and shapes). The component must be displayed on the index finger with the VTPlayer, so it is inverted for left-handled users. The experimenter shows the user an example of dragging by the mouse. Before dragging the user, the experimenter must advise him to hold strongly the PHANToM to prevent injuries. The user must be instructed that he could click the PHANToM button anytime to be given some help on the directions he can go, the bump is bigger if the user has never gone in the given direction. The user is given the chance to ask questions about each of the components until he is comfortable with navigating the circuit and naming the components from each of the representations.

Fig 4.2 The user has the PHANToM in the dominant hand and the VTPlayer in the other

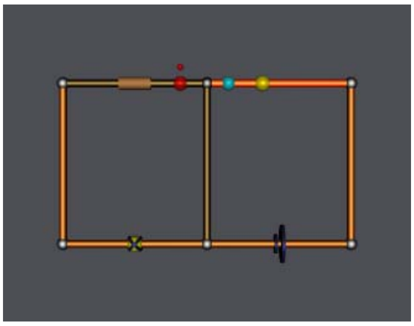

Figure 4.3: Example circuit.

Then the tests began. In this experiment, both users (children and teacher) can use the visual representation of the circuit. Only the visually impaired children use the haptic representation, with a PHANToM on the dominant hand and a VTPlayer on the other hand. Two conditions were tested:

- in the first one the children uses the software to explore the circuit. He's given no information from the teacher.
- in the second one the children uses the software to explore the circuit. He can ask all the information he wants to the teacher. If he asks for the component name, he must make a guess before the teacher gives him the correct answer (so that we can count the right answers). If the user doesn't explore the whole circuit, the teacher can tell the user and propose him to show him with the mouse guidance.

The user is presented 6 circuits among the 7 designed (figure 4.4) in random order, using alternatively condition 1 and condition 2 (counter-balanced among the users). The user is instructed to:

- say the component he feels when he passes on a component.
- describe the circuit shape
- take care on the time spent on the task

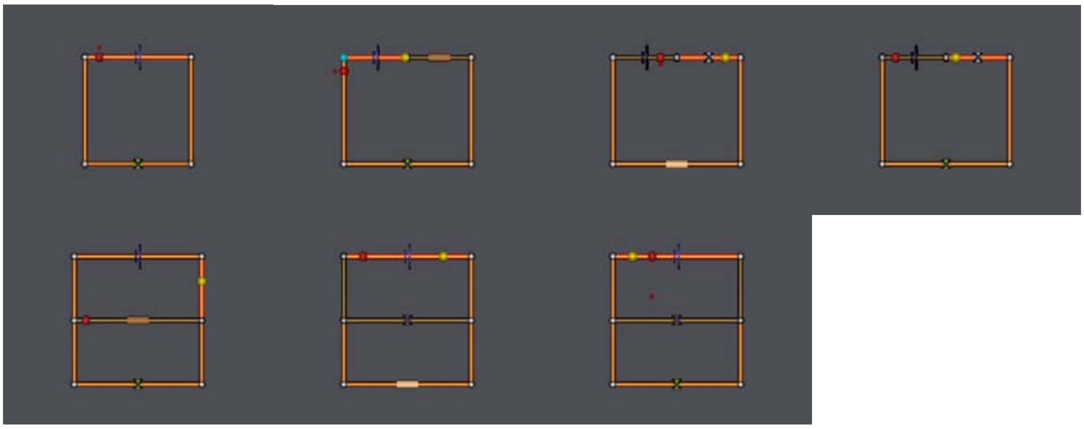

Figure 4.4: 7 circuits designed

When the task is completed the user must fill the post-questionnaire.

4.4.4 Post-test questionnaire

See appendix 2.

4.4.5 Measurements

- video-supported observation
- logging
- comparison to usual teaching method (with other tools like models or relief drawings)
- comparison to how sighted pupils carry out the task

4.5 Results

4.5.1 General usability

- Most of the users who still have partial vision prefer using their partial vision for exploration, so they don't use optional haptic guidance systems.
- Some users with partial vision decide to not use their partial vision.
- Blind users have difficulties to recognize non trivial shapes.

4.5.2 Exploration and navigation

Blind users had serious difficulties concerning navigation whereas users with partial vision had no problem with that. The reason is that almost all the users used their partial vision to explore the circuit. So these users didn't use the navigation cues (on the PHANToM or on the VTPlayer), didn't do any errors about shape recognition, and all felt it is easy to explore the circuit completely. Some of them told the circuit shape before having explored the circuit completely. Only one user (user 6) didn't use his partial vision, and used the PHANToM guided PICOB at junction to explore the circuit, and she did one shape recognition error: she felt two squares one next to the other in spite of two rectangles one over the other.

The blind users had difficulties to understand shapes more complicated than a simple square. Sometimes they don't explore the whole circuit, and sometimes they can't connect the parts they have explored. User 5 tried to use the guided PICOB but didn't felt it could help her. She tried to start exploring at the lower-left corner. She had no problem to explore the circuits completely and name the components, but she had difficulties to describe the shape. The two other users only recognized squares.

Concerning the components recognition, most of the users recognized them without any problem. Only three users made errors (users 9, 10 and 13).

The user 9 had difficulties to remember the components names, especially the resistor. He made three errors. After the 3rd circuit he had to explore he understood that the component symbol on the VTPlayer remains while he is on the component. From this time he used the VTPlayer to recognize the components and did no more errors.

The user 10 recognized a battery instead of a lamp on the circuit 6 (second he explored). However he felt one bump on the PHANToM, so he could have mixed up the codes significations. He hesitated three times on the circuit 4 (first one he explored) and one time on the two next circuits he explored (1 and 3).

The user 13 had difficulties with the components. On the first circuit he explored (number 5), he answered lamp instead of resistor while he recognized a square shape on the VTPlayer and two bumps on the PHANToM. He answered battery instead of lamp while he felt a cross on the VTPlayer and 2 bumps on the PHANToM. He clearly has problems with the half-guided PICOB. We asked him to rely more on the VTPlayer pattern to recognize the components. He seemed to have forgotten the meaning of the pattern so we reminded him the signification of the patterns. After that he hesitated once by circuit, and did an error on the circuit 2 (5th he explored). The hesitations are most of the time between lamp and resistor.

4.5.3 Learnability

The experiment begins with a learning session. Users start with touching and exploring the PHANToM and VTPlayer devices. Then they had to play with demo softwares: icons demo for the VTPlayer, and the Sensable's Dice Demo for the PHANToM. The user is instructed on the purpose of the devices, how to take them and how to use them. This learning phase lasts about 10 minutes, until the users seem ready to use the devices.

Then before beginning the tests, they had to explore an electric schematic that contains the three components possible. The experimenter explains the user all the interactions available in the software. The user is instructed to explore the circuit until he feels ready to recognize the three kinds of components, and he feels he can navigate in the circuit. This phase lasted 5 to 10 minutes.

Even if the learning was not tested in our experiment, some users who made errors for the first circuits did fewer errors after some experiment with the devices and the software. For example the user 9 did 3 recognition errors for the component on the first three circuits he explored. Then he felt more comfortable with the VTPlayer than with the PHANToM to recognize the components, and then did no more errors on the three circuits left.

4.5.4 Assistance

The help from the teacher was useful. Some users (users 3, 9 and 13) had difficulties to recall the components names and their representation. The teacher was useful to remind them the names and representations.

We noticed that most of the time the users didn't need assistance. The user 12 had difficulties to recognize the shape and the components, but didn't want help from the teacher as he felt he had to find by himself. In the collaboration condition the teacher gave him the answer when he made a mistake.

4.5.5 Ability to complete the task

All the users managed to complete the task, even though some users made some errors for shape and components recognition.

Some users (mostly the ones with partial vision) explored the circuits very quickly, and did not take more than 15 minutes to recognize the 6 circuits (shape and components). Some others needed between 20 and 30 minutes to complete the task (users 12 and 13).

4.5.6 Evaluation issues of co-operation

Guidance

- Blind users (users 6, 12 and 13) had difficulties to explore the whole circuits. The experimenter had to tell them to continue to explore in collaboration condition. However the users still had problems with identifying the circuit shape.
- 7 users (users 1, 2, 4, 7, 8, 11 and 13) preferred to use the PHANToM (half-guided PICOB) rather than the VTPlayer (icons) to identify the components.
- The guidance of the PHANToM by the mouse was used for 3 users (users 10, 12 and 13). Only the user 10 found it useful, whereas he had a partial vision, and the two others are blind.
- 5 users (users 3, 5, 6, 12 and 13) used the directional cues. 3 of them found them useful : user 6 who had partial vision but didn't used it, users 12 and 13 who are blind. The user 5 is blind and didn't found it useful. The user 3 had partial vision, didn't found it useful but didn't make any errors.

Common ground

6 users (users 1, 2, 3, 4, 12 and 13) had poor knowledge about electric circuits. All the users know what an electric circuit is, and know what is a lamp and a battery. Only the 6 users cited don't know what a resistor is, however they were instructed to answer "the other component" if they did not recall the name "resistor".

Awareness

The users that navigate with the PHANToM could be aware of the other user's position in two ways. The first one is the red ball that represents the mouse's position on the circuit. The user must have a partial vision to be able to see the visual cursor. The other way is to use the mouse guidance so that the PHANToM is attracted by the mouse. However this feature is activated by the keyboard, so it is supposed to be used by the second user. The Second user can see the PHANToM's projection on the circuit as it is represented as a yellow ball.

Inclusion

Initiative: the children always take the initiative. They consider the experiment as an exercise, and so most of the time they feel it is up to them to complete the task. Some users (user 5 and 12) refused help when the teacher proposed it.

Involvement: the two scenarios do not allow the same rate of involvement concerning the teacher. In the condition without collaboration, the teacher only observed the children's exploration. In the collaboration condition, his role was mainly to correct the children when he made a mistake. He proposed help when he felt the children needed it. However it happened a few time. So the users were more involved in the task than the teacher.

4.6 Discussion and conclusions

The experiment carried out aimed at evaluating the Electric Circuit schematics exploration software for visually impaired children we have designed on top of the MICOLE architecture. Another system to explore schematics has been developed in the project TeDUB [28], but the haptic modality is limited: it only uses a standard force feedback joystick.

The tests use both a PHANToM and a VTPlayer mouse as haptic devices, at the opposite of the preliminary tests we already have conducted [29]. The information is displayed on the two devices at the same time; it is up to the user to choose the modality he wants to use to get the information. Half of the users used one device and the other half used the second one.

The information given with the PHANToM are guided PICOB [26] for directions and half-guided PICOB for components. On the VTPlayer we use the tactile icons we have design for directions [25] and for components.

The experiment was design to encourage the collaborative aspect; however users took the experiment as an exercise and so didn't ask for help, and even refused help when specifically offered.

Both users with partial vision and blind users took part of the experiment. The users with partial vision didn't have any problem to recognize the circuit shape and identify the components. Most of them used their partial vision, which was sufficient to complete the task. One user didn't use her vision and managed to complete the task, using the directional cues.

At the opposite, blind users had difficulties to recognize the circuit's shape. The lack of reference point may be the most obvious explanation, as users were not able to link the different part they explored. A good improvement would be to put labels at the junctions. These labels could be represented as icons on the VTPlayer, as text on a Braille display; the name could be used with a speech output system too.

Most of the problems concerning the components recognition were due to memory problems. Users didn't remember the name "resistor" or didn't remember the pattern on the VTPlayer or the number of bumps on the PHANToM. In that case the collaboration was successful because in the learning condition, the teacher told the user the problem and more or less quickly the users didn't do the errors anymore.

5. MAWEN

UPMC/ULINZ

5.1 Executive Summary

This report documents the evaluation of the MAWEN application – Mathematical Working Environment – done by ULINZ in July and September, and by UPMC in September 2007. Also documented is a second evaluation cycle carried out at the University of Linz in December 2007, which was done according to a recommendation of the final review of the MICOLE project. Within the first evaluation cycle, the application was evaluated in 5 schools (2 in Austria, 3 in France), with a total of 14 pupils (9 in Austria, 5 in France), and 8 teachers (5 in Austria, 3 in France). Within the second cycle, MAWEN was evaluated with 5 grown-up people, all blind, with good experience in reading Braille and using synthetic speech output.

The two evaluation cycles differ in that the first one is more like a guided tour through the application, with a questionnaire about the acceptance of the system, whereas the second cycle is an evaluation centred around concrete tasks to be performed after being introduced to the software.

After a short account of the MAWEN application we describe the tests performed at the various locations. We then give a summary of the results of our tests and of the interviews we had with the pupils and teachers involved. The report closes with a list of recommendations we derive from the evaluation.

5.2 Background and objective

Within Work Package 1, we carried out extensive interviews with blind pupils, their teachers, their parents, and their sighted school mates. The goal was to find out their needs in terms of collaborative, educational software. One of the results of these studies was an urgent need for an improvement of access to Mathematics for blind pupils and students: Even in cases when they were able to do Mathematics quite well with their special equipment, sharing mathematical contents with their teachers or peers proved extremely difficult or even impossible. As a consequence, we decided to develop an application to address the problem within the MICOLE project.

The studies which led to the decision to develop a mathematical collaborative application are documented in Deliverables D1 and D2. Extensive documentation on the MAWEN application can be found in Deliverables D11 and D13.

5.3 Application

ULINZ and UPMC are developing conjointly the MaWEn application, which is a scientific documents editor. It is intended to enable sighted and visually impaired individuals (Braille readers) to work together on a document with scientific contents using each their natural representation of formulas (Braille Mathematical Code for the blind partner, and graphics for the sighted). For instance, users may be a blind pupil and sighted persons from her/his environment (teachers, peers, parents). Documents are of mixed contents: text and mathematical formulas. The pupil may navigate in these formulas and edit them. The objective of the reported work was to evaluate 4 of the main features of MaWEn:

- Synchronisation of formulas in Braille and Graphics;
- Bi-directional pointing possibilities;
- Navigation through formulas by collapse and expand functionality synchronised with both views;
- Support of mathematical manipulation.

In addition, the user can select a Braille Mathematical Code among several supported by the UMCL (Universal Maths Conversion Library). At the time of the tests, UMCL was supporting French (revisions 1971 and 2001), Marburg (German), Italian and British (beta version).

MaWEn is implemented in the Mozilla Framework. It is "self-Brailling" (i.e., does not need a screen reader to work for a blind user), but it supports screen readers also (however, in that case there is a reduced number of functionalities). This application is documented in Deliverable D13.

To perform these evaluations, 2 MaWEn pre-prototypes have been used. The first one, called MaWEn-d3, has been developed from MaWEn components, in order to evaluate the 3 first features listed above, and the second one, MaWEn-d1, was especially designed to demonstrate the support of mathematical manipulation through several examples of standard mathematical tasks (it was Documented in Deliverable D11). *Note: MaWEn-d1 was only tested in Linz.*

The MaWEn-d3 prototype allows to display a formula (chosen from a number of formulas prepared in Canonical MathML format), and to access it visually through the graphical rendering, and simultaneously in Braille on a Braille display. Additionally, a Braille fake view shows on the screen the Braille representation. A screen shot is presented in the following figure (*Figure 1*):

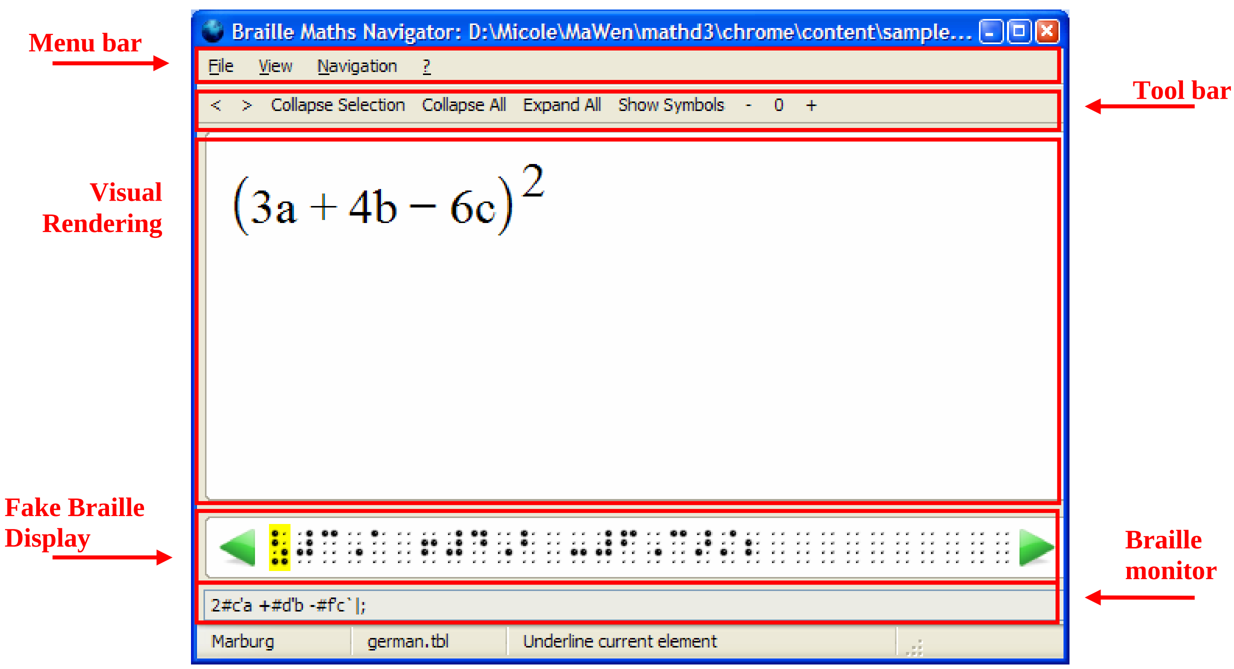

Figure 1: MaWEn-d3 User Interface

5.4 Evaluation

5.4.1 Participants

First Cycle (July to September 2007, ULINZ and UPMC)

ULINZ

The teachers and pupils involved in our evaluation come from two schools for the blind:

- LLH (Landeslehranstalt für Hör- und Sehbildung = Municipal School for Education of Hearing and seeing), in Linz: 2 sighted teachers, 2 visually impaired pupils (low vision), aged 15 and 14 years, respectively
- BBI (Bundes-Blindenerziehungsinstitut = Federal Institute for the Education of the Blind), Vienna: 3 teachers (2 sighted, 1 blind), 7 pupils (5 blind, 2 visually impaired), aged 13 to 21 years

The evaluation was originally planned to take place in May and June 2007. However, due to delays in the implementation of the software, we decided to postpone it, originally to September 2007. However, in order to get some feedback about weaknesses to work on already in Summer, we decided to do the smaller evaluation – navigation support only, in Linz, – in the beginning of July, the main part – navigation and manipulation support, in Vienna, - in mid-September 2007.

UPMC

UPMC initially planned to perform evaluations of MAWEN in 3 Schools for the blind (Rambouillet, Loos, Angers) and also in 1 mainstream secondary school (Paris). These 4 schools have been chosen as they participated in the field study carried out by UPMC about collaborative work in Maths by Blind pupils in the middle of the project (spring 2005) and reported in Deliverable D8. They were all interested to test MAWEN as a new assistive tool for helping blind pupils to learn mathematics in collaboration with their sighted/blind schoolmates and/or teachers. Because of technical difficulties in the implementation process, the evaluation could not take place as initially planed in May/June 2007, so we had to target a very narrow period between September 10 and September 30, 2007. After contacting the four schools mentioned above, we could make our plan of evaluation. Unfortunately the Institute Montéclair from Angers could not participate in our evaluation, not because of a lack of interest but because of an impossibility to find any free time until the end of September 2007. Finally, the evaluations have taken place in the following three schools (Paris, Rambouillet and Loos):

- College Buffon, Paris: 1 sighted teacher, 1 blind pupil (12 years old).
- UPI Louis Bascan, Rambouillet (Unité Pédagogique d'Intégration, a special classroom for children with disabilities integrated in a mainstream school): 1 sighted teacher, 2 blind pupils (16 years old).
- ERDV, Loos (Établissement Régional pour Déficients Visuels): 1 sighted teacher, 2 blind pupils (18 years old).

Second Evaluation Cycle (ULINZ, December 2007)

This time, we chose five test persons who are grown-up, blind people with a good experience in reading Braille and in using synthetic speech output, and with a rather high mathematical level. The reason why we did not work with pupils in special education, as we had done in the first cycle, was that we got the impression that the pupils known to us were mostly not at a mathematical level sufficient to evaluate the algebraic aspects of our Manipulation Support (see tasks “Expansion1” and “expansion2”, below).

Three of our test persons, S2, S3, and S5, are students studying at our University, supported by our student support centre. S1 also studied in Linz supported by us, but she finished her master study in 2006. Finally, S4 finished his grammar school education, in a mainstream environment, in the current year, 2007.

Index	Gender	Age
S1	F	28
S2	F	21
S3	M	27
S4	M	19
S5	M	23

Context

Evaluation Cycle 1

ULINZ

Monday, the 2nd of July 2007: LLH, Linz

- 2 visually impaired pupils (P8, P9)
- 2 sighted teachers (T4, T5)

Wednesday, the 12th of September 2007: BBI, Vienna

- 5 blind, 2 visually impaired pupils (P1-P7)
- 2 sighted, 1 blind teachers (T1-T3)

Material

- At the LLH Linz:
  - one laptop PC with standard keyboard, mouse, and screen, and a Braille display (BrailleStar 40), with MaWEn-d3, for navigation and synchronisation support.
- At the BBI Vienna:
  - one laptop PC with standard keyboard, mouse, and screen, and a Braille display (BrailleStar 40), with MaWEn-d3, for navigation and synchronisation support.
  - one desktop PC with a Braille display (Papenmeier 2D Screen), with the Jaws screen reader and MaWEn-d1, for manipulation support.

UPMC

Tuesday, the 18th of September 2007 at 11h30: Collège Buffon (Paris)

1. 1 blind pupil (P10);
2. 1 sighted teacher (T6);
3. Remark : the bi-directional synchronisation could not be tested because the teacher was not available at the same time as the pupil

Tuesday, the 25th of September 2007 at 15h50: UPI Louis Bascan (Rambouillet)

- 2 blind pupils (P11 and P12);
- 1 sighted teacher (T7);

Wednesday, the 26th of September 2007 at 13h30: ERDV (Loos)

- 2 blind pupils (P13 and P14);
- 1 sighted teacher (T8);

Material

- one computer (laptop) with a standard keyboard and a standard screen, MAWEN-d3 for navigation and synchronisation support
- one Braille display of brand "BrailleNote" which could serve to the blind user to read a formula and also to mark some part of it.

Evaluation Cycle 2

This took place entirely in Linz, with the test persons detailed in the previous section. The tests were carried out from December 7 to December 17 2007. With the exception of S4, all tests were arranged at a computer lab at our university – S4, being a pupil who does not have a direct connection to our university, was visited by one of our staff members, such that we did the test in his domestic environment.
For the manipulation-oriented tasks, all the students except for S2 used their private notebook computers, with Braille and speech output, driven by the screen Reader Jaws. S2 wanted to work on a machine of our department, because she did not like to install our software on her private machine before it would have proved useful to her. The navigation-oriented tasks, however, were performed on machines and Braille displays of our lab, because it would have been complicated and time-consuming to install the necessary MAWEN components on foreign computers.

5.4.2 Procedure and tasks

First Evaluation Cycle

Initial contacts of schools

ULINZ: It was very easy to contact the two schools for evaluation, because we maintain contacts with them for almost 15 years; also, the teachers in question are aware of our efforts to support blind pupils in dealing with Mathematics, while the pupils were not – they were introduced to the matter not before our actual evaluation sessions. The dates were agreed upon by email, whereby a short introduction to the problem field was communicated to the teachers. They were selecting appropriate pupils for us.

UPMC: To contact our prospective participants in the evaluation of MAWEN, we used mainly phone communication, because all of them were knowing the objective of our software which we had already explained to them in some e-mails and phone conversations, and even some short demonstrations during the months of April and May 2007. It was also the fastest way of communication which permitted us to book the above-mentioned dates of our evaluations.

Development of the test tasks

We explained to the responsible persons who were ready to participate in our evaluation that it would have not the aim to ask to the blind pupils to solve some mathematical exercises but just to read and navigate in some formulas included in their schoolbooks for the current school year. This is true at least for the navigation component of MAWEN – the manipulation component, which was only evaluated in Vienna with 3 pupils and 3 teachers, did include some solving of exercises. As our objective was also that the formulas would correspond to the actual grade of studies in Mathematics of the blind pupils, we requested from their teachers some examples of formulas, which they sent us by fax. That collaboration of the teachers helped us to pre-load those formulas into our software before the evaluation, such that the evaluation could be realized in quite a short period of time.

Pre-test of stability and usability

After pre-loading the formulas into our software we have tested if our Braille devices - BrailleNote and BrailleStar - could be normally activated, and if the formulas could be navigated by the hot keys and the combinations of keys assigned by MAWEN.

- Training with hardware or application just before tests
  Before each evaluation we have trained our hardware and applications.
- Testing the procedure
  Evaluation procedures were tested before evaluation sessions.

Evaluation Procedures

Presentation of the system to the teachers

- Short introduction: Why MAWEN? Basic information on the MICOLE project
- Description of basic functions (load exercise, Collapse/Expand the whole formula, Collapse/Expand selection, point and click)
- Short mention of limitations and of planned extensions
- Description of evaluation steps

Estimated duration: 10 mn

Presentation of the system to the pupils

Similar to the presentation to the teachers, but less info about the project etc.
Estimated duration: 10 mn

STEP 1: Practical exercises

PHASE 1: To every pupil, between two and five examples of mathematical formulas with different complexity will be presented (the various formulas are listed in Appendix 3A). The objective of this task won't be to resolve those formulas but just to read, navigate, and understand them.

During this phase each blind pupil should work alone without any intervention from us or from his/her teacher.

PHASE 2: When the pupil is finished with considering a sample expression by navigation, the bi-directional synchronisation through point and click will be tested. The pupil will point at a certain spot within the formula with the cursor routing buttons of his/her Braille device, and the teacher reports whether (s)he can localize the spot on the screen. The other way round, the teacher will point at a spot within the formula with the mouse, and the pupil will tell whether (s)he can distinguish the spot in Braille.

Estimated duration: 20 mn

STEP 2: Interviews after the tests:

1) Interview with the teachers
2) Interview with the pupils

Second Evaluation Cycle

Evaluation Procedure

Both MAWEN components, Navigation and Manipulation Support, were first introduced to the test persons through a guided tour similar to the one used in the first evaluation cycle. Afterwards, the test persons were given some concrete tasks, which they were to perform without our assistance, as far as possible.

The concrete tasks

Following is a detailed description of the tasks given to the test persons. After every formula, a descriptive name, used to refer to the task later on, is shown in parentheses.

Navigation Support

Two expressions are presented to the student as an equation. The student is to decide whether the expressions are identical or not. In case they are not, (s)he shall identify the spots where the expressions differ. The expand/collapse facilities provided by the software should be utilized.

Two identical expressions

$$\frac{4a-9b+6c}{-12a+3b-c}+\frac{-4r+3s-7t}{3r-s+5t}=\frac{4a-9b+6c}{-12a+3b-c}+\frac{-4r+3s-7t}{3r-s+5t}$$

Two slightly different expressions

$$\frac{12u-9v+3w-4x}{-9u+2v+6w-x}-\frac{-4m+3n+5o-p}{3m-2n+5o-6p}=\frac{12u-9v+3w-4x}{-9u+2v+9w-x}-\frac{-4m-3n+5o-p}{3m-2n+6o-6p}$$

Two identical expressions

$$\sqrt{3x^2-12xy+9y^2}+\sqrt{-4x^2+15xy+16y^2}=\sqrt{3x^2-12xy+9y^2}+\sqrt{-4x^2+15xy+16y^2}$$

Two slightly different expressions

$$\sqrt{4a^2b-13ab+5b^2}-\sqrt{-19a^2+22ab-7b^2}=\sqrt{4a^2b-13ab+25b^2}+\sqrt{-19a^2-22ab-14b^2}$$

It is documented:

- Whether or not the student was able to accomplish the task, i.e., to decide whether the expressions are identical or not.
- In case the student found differences, whether or not (s)he found the right ones.

It is measured:

- How much time the student needed to fulfill the task.
- How often (s)he requested assistance, and what exactly was asked by him/her.

Manipulation Support

Each exercise should be done first by a method the pupil/student is familiar with, then by using our software. The expressions to be used for both variants are different, but of equal complexity.

Arithmetics

Addition, subtraction, and multiplication of integers and of floating point decimal numbers is done here.

Addition – the student shall use the “Prepare Addition” and „Simple Addition” wizards

- To be done by traditional methods:
    - 625 +34 +219 (addition_integer_traditional)
    - 126,3 +19,84 +46,8 (addition_decimal_traditional)
    - 235 +681 +3528 +4916 +681 +47 +3096 +541 (addition_integer_long_traditional)
    - 521,34 +16,438 +29,317 +6,87 +429,6 +3,047 +218 (addition_decimal_long_traditional)
- To be done with our software:
    - 1385 +419 +2106 (addition_integer_mawen)
    - 15,78 +3.411 +0,18 (addition_decimal_mawen)
    - 1635 +981 +47 +2518 +307 +269 +73 +2304 (addition_integer_long_mawen)
    - 12,498 +0,83 +417,5 +768, +93,516 +104,7 +8,615 (addition_decimal_long_mawen)

Subtraction – the student shall use the “Prepare subtracttion” and the „Simple subtraction” wizards

- To be done with traditional methods:
    - 2534 -368 (subtraction_integer_traditional)
    - 125,81 -47,069 (subtraction_decimal_traditional)
- To be done with our software:
    - 4281 -695 (subtraction_integer_mawen)
    - 119,63 -0,217 (subtraction_decimal_mawen)

Multiplication – use the “Multiply” wizard

- To be done with traditional methods:
    - 3284 * 916
- To be done with our software:
    - 4935 * 327

Algebra

Two algebraic sums are to be multiplied, and the result is to be simplified. The “Multiply Parentheses” and the “Simplify” wizards are to be used.

- To be solved by traditional method:
    - (-3a +5b -4c) *(6a +9b -c) (expansion1_traditional)
    - (12r -4s +7t) *(-2r +s +3t) (expansion2_traditional)
- To be solved by our software:
    - (x +3y -7z) *(-2x -5y +6z) (expansion1_mawen)
    - (-12u +9v –w) *(3u +4v -6w) (expansion2_mawen)

What is documented:

- Whether the student was able to accomplish the task – simple computation errors are not counted as failure.
- In case there were problems doing the required computation exercises with our software, where the problems were located.

What is measured:

- The time the pupil/student needed to work with his/her traditional methods, and the time needed to do it with our software.
- How often (s)he requested help, and, in case (s)he did, which kind of assistance was asked for.

Interviews

Through our interviews, we wanted to find out how the software is accepted among the pupils and the teachers. Of special importance was the question whether they felt an improvement of their mathematical work compared to their traditional way of dealing with the subject. Equally important for us was to find out whether the software would provide improvements in collaboration between blind pupils and sighted teachers. Finally, we were interested in questions of software performance, and in getting an idea how easy it was for pupils and teachers to learn the usage of our programs.

Part 1. Navigation and Synchronisation

Pupils' questionnaire

1. With which software do you currently work in Mathematics?
2. Do you use software designed especially for the education of blind pupils in Mathematics? (yes/no)
3. Did you ever consider to use such software? (yes/no)
4. If yes, which one?
5. If yes, how satisfied were you with that software? (Marks: 1 = very much satisfied, 5 = not at all satisfied)
6. How easy, or how difficult, was it for you to get acquainted with our software? (Marks: 1 = very easy, 5 = very difficult)
7. How do you assess the keyboard shortcuts chosen by us? (Marks: 1 = very well designed, 5 = very badly designed)
8. Which changes to the keyboard shortcuts would you suggest?

9. Do you think you understood the formulas with our software easier than with the methods you used until now? (Marks: 1 = it was much easier, 2 = it was somewhat easier, 3 = it was as cumbersome as usual, 4 = it was even more cumbersome than usual, 5 = it was much more cumbersome than usual)
10. Did you get the impression that the synchronisation between Braille and visual representation was working? (Marks: 1 = worked very well, 5 = worked very badly)
11. Do you feel that through synchronisation you can easier communicate with your teacher? (Marks: 1 = absolutely, 5 = noticed no difference)
12. How do you assess the speed of the system? (Marks: 1 = very fast, 5 = very slow)
13. Do you deem the speed of the system sufficient? (Marks: 1 = completely sufficient, 5 = not at all sufficient)
14. Do you find the software helpful for your education altogether? (Marks: 1 = very helpful, 5 = not at all helpful)
15. Which changes, improvements, or extensions of the software would you desire? (for every item you claim, please indicate how important it is for you: 1 = very important, 2 = moderately important, 3 = not so important)

Teachers' questionnaire

1. Which software do you currently use in your maths teaching?
2. Do you use software that is designed especially for the education of blind pupils in Mathematics? (yes/no)
3. Did you sometimes consider to employ such software? (yes/no)
4. If yes, which one?
5. If yes, how satisfied were you with that software? (Marks: 1 = very much satisfied, 5 = not at all satisfied)
6. How easy, or how difficult, was it for you to get acquainted with our software? (Marks: 1 = very easy, 5 = very difficult)
7. How do you assess the keyboard combinations assigned by us? (Marks: 1 = very well designed, 5 = very badly designed)
8. In which respect would you change/improve the keyboard shortcuts?
9. Do you think that our software may support a blind pupil in understanding mathematical expressions? (Marks: 1 = absolutely, 5 = absolutely not)
10. Did you notice an improvement in your pupils' understanding of mathematical expressions compared to their traditional work during the tests? (Marks: 1 = marked improvement, 2 = partial improvement, 3 neither improvement nor complication, 4 = partial complication, 5 = marked complication)
11. Did you get the impression that the synchronisation between Braille and visual representation did work? (Marks: 1 = it worked very well, 5 = it worked very badly)
12. Did you find the synchronisation helpful for your teaching? (Marks: 1 = very helpful, 5 = not at all helpful)
13. How do you assess the speed of the system? (Marks: 1 = very fast, 5 = very slow)
14. Do you deem the speed of the system sufficient? (Marks: 1 = completely sufficient, 5 = not at all sufficient)
15. Do you find the software helpful for your teaching altogether? (Marks: 1 = very helpful, 5 = not at all helpful)
16. Which changes, improvements, or extensions of the software would you

desire? (Please assign a priority to each of the items claimed by you: 1 = high, 2 = medium, 3 = low priority).

Part 2. Manipulation

Pupils' questionnaire

1. With which software do you currently work in Mathematics?
2. Do you use software designed especially for the education of blind pupils in Mathematics? (yes/no)
3. Did you ever consider to use such software? (yes/no)
4. If yes, which one?
5. If yes, how satisfied were you with that software? (Marks: 1 = very much satisfied, 5 = not at all satisfied)
6. How easy, or how difficult, was it for you to get acquainted with our software? (Marks: 1 = very easy, 5 = very difficult)
7. How do you assess the keyboard shortcuts chosen by us? (Marks: 1 = very well designed, 5 = very badly designed)
8. Which changes to the keyboard shortcuts would you suggest?
9. Do you feel that calculating was easier for you with our program than with the methods you used until now? (Marks: 1 = it was much easier, 2 = it was somewhat easier, 3 = it was as cumbersome as usual, 4 = it was even more cumbersome than usual, 5 = it was much more cumbersome than usual)
10. How do you assess the speed of the system? (Marks: 1 = very fast, 5 = very slow)
11. Do you deem the speed of the system sufficient? (Marks: 1 = completely sufficient, 5 = not at all sufficient)
12. Do you think that the program takes away too much computational work from you? (Marks: 1 = absolutely, 5 = not at all)
13. Do you feel to be patronized by the program, such that you would like to do calculations in a way different from the one dictated by the software? (Marks: 1 = not at all, 5 = absolutely)
14. Do you find the software helpful for your education altogether? (Marks: 1 = very helpful, 5 = not at all helpful)
15. Which changes, improvements, or extensions of the software would you desire? (for every item you claim, please indicate how important it is for you: 1 = very important, 2 = moderately important, 3 = not so important)

Teachers' questionnaire

1. Which software do you currently use in your maths teaching?
2. Do you use software that is designed especially for the education of blind pupils in Mathematics? (yes/no)
3. Did you sometimes consider to employ such software? (yes/no)
4. If yes, which one?
5. If yes, how satisfied were you with that software? (Marks: 1 = very much satisfied, 5 = not at all satisfied)
6. How easy, or how difficult, was it for you to get acquainted with our software? (Marks: 1 = very easy, 5 = very difficult)
7. How do you assess the keyboard combinations assigned by us? (Marks: 1 = very well designed, 5 = very badly designed)
8. In which respect would you change/improve the keyboard shortcuts?

9. Do you think that our software may support a blind pupil in performing calculations? (Marks: 1 = absolutely, 5 = absolutely not)
10. Did you notice during the tests that your pupils could do mathematical calculations easier compared to their traditional way of working? (Marks: 1 = marked improvement, 2 = partial improvement, 3 neither improvement nor complication, 4 = partial complication, 5 = marked complication)
11. How do you assess the speed of the system? (Marks: 1 = very fast, 5 = very slow)
12. Do you deem the speed of the system sufficient? (Marks: 1 = completely sufficient, 5 = not at all sufficient)
13. Did you feel that the software would take too much computational work away from the pupil, or that it even would conceal understanding of mathematical concepts? (Marks: 1 = not at all, 5 = absolutely)
14. Do you find the software helpful for your teaching altogether? (Marks: 1 = very helpful, 5 = not at all helpful)
15. Which changes, improvements, or extensions of the software would you desire? (Please assign a priority to each of the items claimed by you: 1 = high, 2 = medium, 3 = low priority).

5.4.3 Methodology

Evaluation Cycle 1

The user sessions took place in the schools in all cases. In order to avoid installation problems, like library conflicts (it is prototype software), Laptop computers with the installed software were brought to the schools by us. In the Austrian tests it was possible to videotape the sessions, but not in France (the delay was too short to get the necessary authorisations).

During the sessions, the software was presented first. Then the pupils were asked to complete the requested tasks, together with the teachers. At the end the teachers and the pupils were interviewed separately.

In one case (teacher T5 in France) it was not possible to have a meeting with the teacher and the pupil at the same time so the software was presented separately to the teacher and the pupil. As the teacher did not know the Mathematical Braille it was not possible to evaluate the bi-directional synchronisation with her. Nevertheless the rest of the evaluation was done with the researcher playing the role of the pupil so she could actually realise the interview efficiently.

Evaluation Cycle 2

See sectins “Context” and “Procedure and Tasks” above.

Measurement

No measurement was taken in Evaluation Cycle 1.

In Cycle 2, for each task, the time needed by the student to perform was measured. For the manipulation-oriented tasks, the time needed to perform them with traditional methods was also measured, in order to test whether our software would furnish speed-up in performance compared to traditional methods of calculation. It was also measured how often the student requested help during calculation.

5.5 Results

From our tests it could be seen that the application was well accepted and is considered helpful. Pupils, students, and teachers recognize its value over their traditional way of working. However, they express the need of increasing the performance of the software, especially that of the navigation/synchronization component mathd3. Also, they urgently request both application components - synchronisation/navigation on the one hand and manipulation on the other hand - combined, such that features of both may be used throughout the system.
Tables presenting the pupils' and the teachers' answers to the interview questions are available in Appendix 3B.

5.5.1 General usability

Our ultimate goal with MAWEN is to design a software that makes dealing with Mathematics easier compared to traditional methods, primarily for the blind pupil, but also for the sighted teacher or school mate who is to cooperate with the blind pupil. Whereas the pupils and students clearly expressed that they felt a simplification furnished by our software compared to traditional methods, the teachers could not be completely convinced. The same is true for overall helpfulness of the software.
It became apparent that the speed of the software requires improvement, which is especially true for the navigation/synchronization component.
The design of the user interface implemented by us, especially the keyboard commands chosen, was generally considered appropriate.
There was some anxiety expressed both by pupils and by teachers that the manipulation component of MAWEN would take away too much work from the pupils, or that it would patronize them, in that it would force them into a way of calculating different from their personal one.

5.5.2 Exploration and navigation

The various navigation techniques furnished by MAWEN, especially the collapse/expand features, proved to work appropriately, and are well accepted. However, the synchronization between Braille and visual view proved not to work perfectly still.

5.5.3 Learnability

Both pupils and teachers proved in the tests and expressed in the interviews that they had no substantial difficulty learning to use the system.

5.5.4 Assistance

Our assistance was necessary just in terms of explanations about the functionalities of the hot-keys and the combinations of keys permitting to navigate into a formula.

5.5.5 Ability to complete the task

Navigation and Synchronization Tasks

The pupil's task to select portions of expressions in Braille such that the teacher could perceive them, and also the converse task for the teacher to select a piece of a formula by mouse in order to make it apparent for the pupil, tested in Cycle 1, could be

completed most of the time – with some restrictions due to the errors in the synchronisation engine mentioned.
The navigation tasks of Cycle 2, where students had to apply collapse/expand in order to decide whether certain complex expressions were identical or not, could be successfully completed by those who were given them. For reasons of lacking time, S4 could not be given these tasks.
The following table sums up the time needed by the various students to complete those tasks:

Task	S1	S2	S3	S5
comp_frac_ident	2 min 25	2 min 16	2 min 39	2 min 20
comp_frac_diff	2 min 36	2 min 24	2 min 28	2 min 31
comp_root_ident	2 min 12	1 min 58	2 min 7	2 min 3
comp_root_diff	2 min 18	1 min 59	2 min 7	2 min 5

Both S3 and S5 once asked for help on a hot key they did not remember.

Manipulation Tasks

The computational tasks given to those pupils who tested the manipulation component in Cycle 1 could be completed without limitations. The same is true for the calculation tasks in Cycle 2, although, as can be seen from the table below, time did not allow to do every task with every student.
As for the traditional method to do the tasks, we left complete freedom to the students. Everyone chose to use the classical Windows Editor, notepad.exe, in which (s)he developed the calculations as simple text files.

The following table sums up the times needed to do the various computational tasks, both with traditional methods and with our MAWEN software.

Exercise	S1	S2	S3	S4	S5
add_dec_trad	1 min 46	1 min 51	1 min 30	0 min 40	
add_dec_maw	2 min 2	1 min 50	1 min 40	1 min 56	
add_dec_long_trad			14 min 03	2 min 29	17 min 06
add_dec_long_maw			2 min 15	2 min 25	06 min 47
add_int_trad	0 min 50	0 min 56	1 min 02		
add_int_maw	1 min 12	2 min 4	1 min 10		
add_int_long_trad			7 min 20	1 min 9	
add_int_long_maw			3 min 10	0 min 53	
subtr_dec_trad	2 min 9				
subtr_dec_maw	1 min 42				
subtr_int_trad	1 min 9				
subtr_int_maw	1 min 4				
mult_int_trad					15 min 19
mult_int_maw					08 min 06
expansion1_trad	7 min 37			3 min 57	13 min 36
expansion1_maw	9 min 4			6 min 3	03 min 04
expansion2_trad			6 min 14		
expansion2_maw			4 min 20		

It becomes apparent from the table that not in every case calculation through MAWEN was faster than through traditional methods. This is especially true for the

short additions – the ones with three summands, and for the expansions in some cases. On the other hand, with the subtractions and with the long additions, i.e., the ones with seven or eight terms, MAWEN was faster.
It seems that the real benefit of our software becomes apparent with increasing complexity of expressions. In case of very simple tasks, as the additions with 3 terms, the traditional methods seem to be sufficient. The students, although many years ago, did a lot of practice with this kind of calculation in a traditional way, whereas their opportunity to practice in MAWEN was confined to the guided tour prior to testing. this may have caused the observed fact, namely, that here the traditional way was the faster one. In case of the long additions, however, most of the students lost their overview over the calculation somewhere in its course, which explained the extreme slow times up to 14 minutes. On the other hand, MAWEN was designed to guarantee that one does not lose control over the process, even in case of plenty of summands, which explains the fast completion of the long additions.
An interesting case is the subtractions: Although tested immediately after the short additions, where MAWEN was slow, they yielded a slight advantage for MAWEN.
The case of the algebraic tasks, the expansions, is also interesting: From the four expansions that were tested, exactly two resulted in favour of MAWEN, and two in favour of the traditional way.
On the other hand, speed, although very easily measurable, is not the only factor that makes up the effectiveness of a software product, or even its superiority over traditional methods: It was conveyed by the interviews we did in Cycle 1, but also by some informal talks we had with our test persons in Cycle 2 that they appreciated the computation method offered by MAWEN, because they consider it a more structured, systematic and stress-free approach compared to there conventional methods of doing calculations.

Collaboration Support

Collaborative features of the navigation/synchronization component was extensively tested in the first evaluation cycle: As outlined earlier, after the guided tour through the application, pupils together with their teachers utilized the synchronization ability of the system to point at spots in an expression which the respective other party could distinguish. This feature, although not yet perfectly working in every case, proved that people can work at one and the same formula, even if they are using representations not known, or even inaccessible, to the other party.
The manipulation component of MAWEN is a collaborative piece of software; first, because it does neither rely on any Braille maths code nor on graphical mathematical representation, but on a code similar to that used in programming languages, which is not ideal, but well understandable for both sides. Secondly, every MAWEN manipulation wizard features a visualization window, allowing a sighted person to view the progress of a calculation done by a blind one. During our guided tour through the Manipulation component we did in the first evaluation cycle, teachers constantly were using this visualization in order to follow our presentations.

5.6 Conclusion

As can be seen from our test observations and from the interview assessments documented, the MAWEN application was well accepted by the pupils and their

teachers, and also by the students with whom we tested it. It is considered helpful, and there is a great interest with the community to see it further developed.
However, several urgent wishes and suggestions for improvement were expressed. Some of these can be seen from our observations during the tests, others can be derived from the interview assessments, and some were expressed in the comments which were given to us by pupils and teachers during the interviews.
Here is a list of the most important suggestions:

- To combine the capabilities of the two MAWEN components: It was observed that features found in one of the components are missing in the other and vice versa, which complicates the use of the system.
- To improve synchronisation between Braille and visual rendering of equations: This works in principle, but still not perfectly. Since this feature is central for collaboration, it is important to work on it.
- To increase the speed of the software: Many test persons remarked that the system performs slowly, which is especially true for the navigation/synchronisation component.
- To develop more UMCL input/output modules: The mathematical Braille codes with which we carried out our tests are not common in every educational environment – this was felt especially with the Marburg Braille code, which was quite common in earlier times in German-speaking countries, but which seems to be more and more neglected in current education of blind children. Hence the need for supporting more “modern” codes arises, a task that should not be difficult because the UMCL architecture makes it relatively easy to introduce new codes.

6. King Pong

6.1 Revisions for WP5-Evaluation

In the FP6 Project Review Report, it was noted that FORTH did not use an adequate number of test participants in the evaluation process for the results to be considered valid. In this context, to accommodate review comments an additional testing process was conducted to support our initial findings, including eight more participants (end-users). A more detailed description regarding the participants' profiles is reported under paragraph 0 "6.4 Participants' Profile". The new test followed the same evaluation process as the previous one, which is described in detail in paragraph 0 "6.5 Process". The findings of the additional usability trials are reported in detail within paragraph 0 "6.6 Evaluation". Finally, the initial test as described in deliverable D15 is presented in paragraph "Appendix 4D, Initial Evaluation" of the Appendix 4D, while all the material related to the evaluation procedure, such as the parents' consent form, the background information questionnaire and the usability evaluation questionnaire, are all encompassed in paragraph "Appendix 4A-4C". It should be noted that since the evaluation took place at the ICS-FORTH usability evaluation laboratory, all participants were Greek citizens and therefore all the documents provided to them were in Greek. As a result, the documents appended in this report are translations of the original versions that were used to carry out the evaluation procedure.

6.2 Background and objective

King Pong exhibits several features which render it suitable for visually impaired people. Firstly, Pong game is very simple to play with rules and mechanics mostly obvious to anyone. Additionally, it is a game with spatially-oriented attention with an inherently simple game scene enabling to investigate augmented auditory representations.

6.3 Application

The King Pong game is a universally accessible game which supports a spatially localized audio environment and force feedback (translating sound into haptic feedback). It may be played either by one player and the computer as opponent or by two players. In two-player mode, the opponents can share the same computer or alternatively play the game over the network. Moreover, the game has been designed to adapt to different levels of visual disability. King Pong also supports recording and playback of game play activities for offline analysis and evaluation.

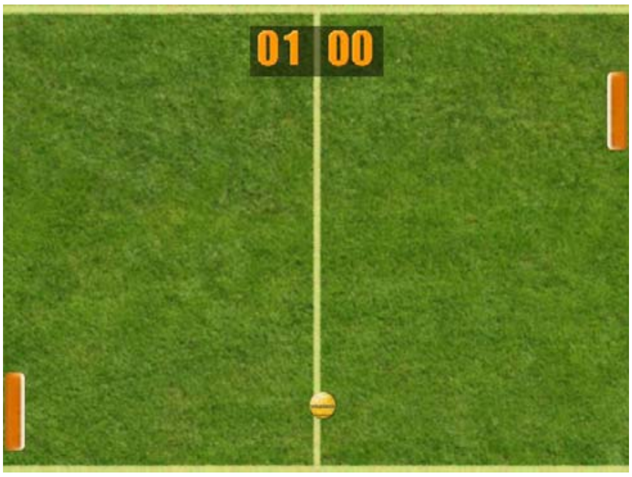

Figure 2: A King Pong screenshot.

6.4 Participants' Profile

For this test we gathered a total of eight participants within the ages of 14 and 17. Of the eight participants, three were female and five were male. Four of them were blind and four were partially sighted. All of our blind participants had at least some experience with BRAILLE and they had some experience with computer usage.
The rest had used a computer only once or twice in their life.

We separated the participants into two groups: Group 1: Blind users, Group 2: Partially Sighted users.

As the experiments took place in ICS-FORTH usability evaluation laboratory, all participants were Greek. In order to assure that children would understand the software interface, which is in English, all children that were selected had adequate English knowledge. In addition, the evaluators would translate any words that were not recognized by the participants.

6.5 Process

The tests were performed within a period of four days, testing two kids per day. In each test, we matched a blind child with a visually impaired one. The purpose of this set-up was to have a blind player collaborate with a non-visual one in the second part of the experiment.

Firstly, we introduced the children and their parents to our lab facilities explaining to them how the test was going to be performed. Since the participants were underage we asked the parents to read and sign a consent form (see a translated version in 0 " 4A, Consent Form"). During the introduction we tried to create a pleasant and non-threatening environment for the children, by encouraging them to ask questions about our set-up and instruments we were going to use to conduct the test. We also stressed to both parents and children that we were not going to test the children's ability, but our software's functionality and usability in order to make it better.

Once they seemed familiarized with their surroundings, we introduced them to the computer that was going to host the game as well as the haptic devices used, the PANTHOM, the Logitech force feedback gamepad, and the BRAILLE pad. We then asked them to fill-out a short questionnaire to assess their overall experience in using a computer and their experience with electronic games. An English translated version of the questionnaire is presented in "Appendix 4B, Background Information Questionnaire".

Since the participants didn't have extended computer usage experience and very little experience with gaming devices, we introduced a training session that lasted about 20 minutes. During that training session, we let the children handle the PHANTOM device and the gamepad controller. We used the "Frictionless Sphere" and "Hello Sphere" examples from Sensable as a demo for the PHANTOM device. For the gamepad, we demonstrated the vibration feeling and how the various functions of the controller work. We also demonstrated the BRAILLE system, which all the blind users were familiar with.

Once the demonstrations had been completed and users became familiar with the input and output devices, the evaluation session was initiated. Each participant was handed a task scenario, explaining the tasks that should be carried out. All the tests that were carried out are explained in detail in "6.6 Evaluation". After completing the test tasks, each participant was interviewed, as described in "6.6.8 Interviews". Finally, the evaluation session was concluded by thanking the user for participating in the test and stating that the test helped to identify areas of possible improvement in the King Pong game.

6.6 Evaluation

The evaluation had three main goals: to evaluate the usability of accessibility of the game menu system, to evaluate how effectively information is conveyed to disabled people by the use of the haptic devices that we used, and lastly to determine whether two people with varying degrees of disabilities could play this game together. For this purpose, the evaluation was divided into three parts as depicted on Figure 3.

In the first part, we tested the usability and accessibility of the game's menu system. We gave each participant a list of five tasks that had to do with navigating through the menu system in order to change certain game options. We then measured how successful they were in completing these tasks.

In the second part of the evaluation we tested the bimanual interaction methods. Each blind participant tested the PHANTOM and the Gamepad bimanual method and then the BRAILLE and the Gamepad bimanual method, while each partially sighted participant tested the Auditory and Gamepad bimanual method and then the PHANTOM and Gamepad bimanual method. We alternatively changed the testing order of the two methods to make sure we didn't introduce any bias. During this part of the evaluation, we paused the game randomly and asked the participants where they thought the location of the ball and the paddle was on the screen to see if they had a clear image of the game. We then tested their success rate on that parameter.

In the third part of the evaluation, we matched a blind participant with a partially sighted participant and had them play against each other, to see if the game could be played with two people with varying degrees of disabilities.

In the end of the three-parted evaluation, we conducted an interview with each participant to gather more information on what they liked, what they disliked, their thoughts on the haptic devices used in the test, and overall on the usability and accessibility of the game.

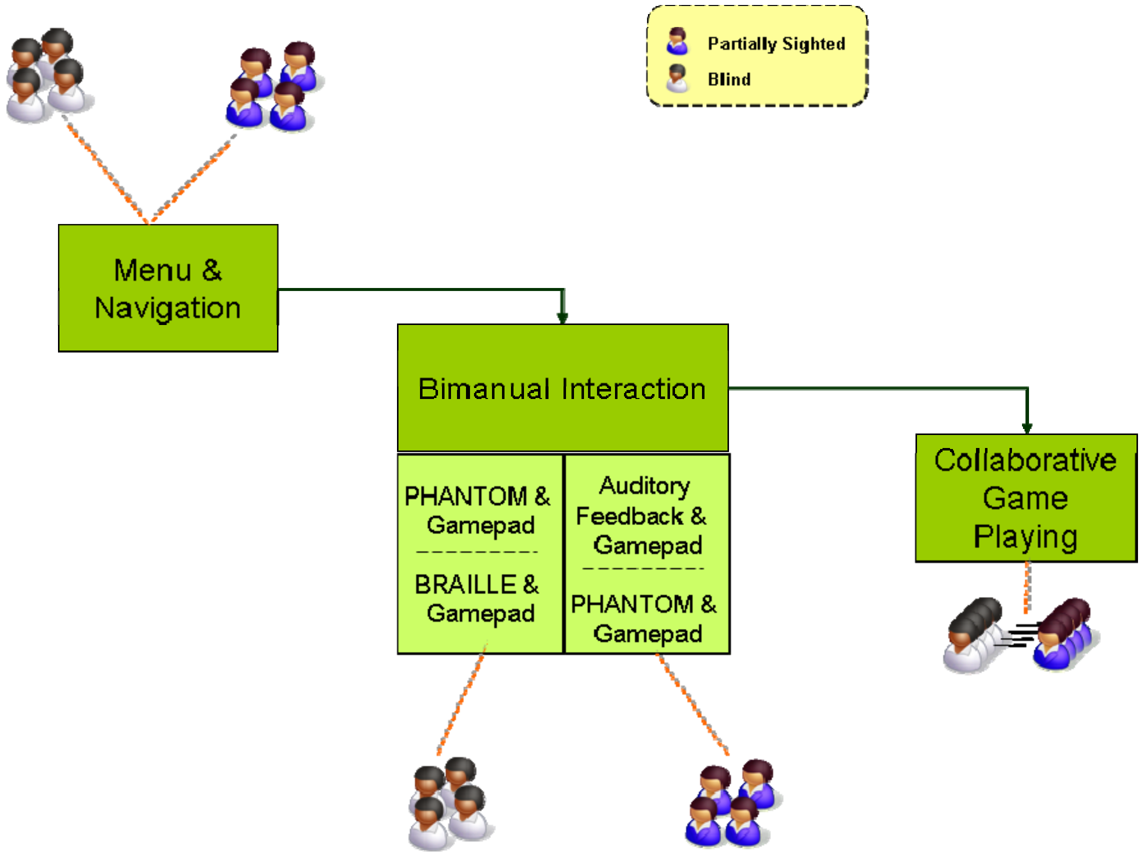

Figure 3 Representation of the Evaluation Setup

6.6.1 Menu and Navigation

The first part of the evaluation focused on the usability and accessibility of the menu system. Mainly, we wanted to test whether the users were able to change the various game set-ups easily through the ‘options’ and ‘select mode’ dialogs in order to adapt the game features to their needs. For this purpose, the following tasks were given to complete:

T1 – Find the option that allows you to play the game against the computer.
T2 – Enlarge the size of the game objects (ball and paddles).
T3 – Select your dominant hand

T4 – Select the Braille Output (for Group 2, we asked them to select the Phantom)
T5 – Quit game

For the first part of the evaluation we chose Jacob Nielsen's [31] rate of success as a measurement, as well as the thinking aloud approach. Table 1 below summarizes the results of this test. Note that S stands for success, F for failure and P for partial success. Partial success was defined as the cases where the users managed to complete the task, but with some direction from the tester.

	T1	**T2**	**T3**	**T4**	**T5**
Group 1: Blind Users					
User 1	S	P	S	P	S
User 2	P	P	S	P	S
User 3	P	P	S	F	P
User 4	P	F	P	P	P
Group 2: Partially Sighted Users					
User 1	S	P	S	P	S
User 2	S	S	S	P	P
User 3	S	F	P	P	S
User 4	P	P	S	P	S

Table 1 Menu and Navigation test results

In total, we observed 40 total attempts to perform the tasks. Of those, 16 were successful and 21 were partially successful to which we give half a point. In order to calculate the overall success rate, we used Nielsen's formula:

Success Rate = (S+(P*0.5))/Total Attempts

Therefore, according to our calculations the overall success rate of the menu system was (16+(21*0.5))/40 = 66,25%.

A comparison of the success rates of the two user groups, blind users and partially sighted users, indicated that partially sighted users had a higher success rate. In more detail, the success rates were:

- Blind users' success rate: (6+ (12*0.5))/20 = 60%
- Partially sighted users' success rate: (10+(9*0.5))/20 = 72,5%

It was not a surprise that the partially sighted users had a higher success rate than the blind users. The initial interview questionnaire showed that our partially sighted testers had more computer experience than the blind users and they also had some gaming experience, so they were more familiar with setting up the options of a game.

However, according to the comments gathered during the test, all the users expressed difficulties when they reached the lower levels of the menu. One of the main reasons for this problem is believed to be the lack of a "Back" button in every menu level. In addition, it occurred from the comments that the users weren't confident as to what they were going to find under each option level, since the words weren't descriptive enough. For example, we asked them what they thought was under the option "Interface" and none of them could guess. Despite the uncertainty, most users were still able to navigate back and forth through the options and choose what they needed.

6.6.2 Bimanual Interaction

Bimanual interaction test included the use of various input and output devices in a variety of setups. The devices used were:

- the PHANTOM device which mimicked the orbit of the ball
- the Logitech gamepad which through force feedback, provided hints about the ideal position of the user's paddle in order to hit the ball, about collisions of the user's paddle with the borders of the game space and finally about successful hits of the ball with the paddle
- the Braille display, conveying all speech messages, including menu options, score announcements, computer opponent moods etc. Furthermore, the first Braille cell of the display has a special purpose. It is used to guide visually impaired players to move their paddle to the correct direction (up / down) in order to hit the ball

Bimanual interactions setups were different among the two different user groups. Blind users were asked to evaluate the game using the PHANTOM device and the Logitech gamepad, as well as with the BRAILLE display and the Logitech gamepad. On the other hand, partially sighted users were asked to evaluate the King Pong game using auditory feedback and the Logitech gamepad, as well as the PHANTOM device and the Logitech gamepad. Therefore, each user was asked to evaluate the software using two different device setups. In order to minimize any learning effects for the second test each user had to carry out and eliminate any bias in the results, we created two subgroups in each group and reversed the order of the tests, as shown in Table 2.

		Test 1	Test 2
Blind	Group 1	PHANTOM - Gamepad	Braille - Gamepad
	Group 2	Braille – Gamepad	Braille – Gamepad
Partially Sighted	Group1	Auditory feedback - Gamepad	PHANTOM - Gamepad
	Group 2	PHANTOM - Gamepad	Auditory feedback - Gamepad

Table 2 Bimanual Interaction Evaluation Setup

In this part children were asked to start the game in single mode. Before starting the evaluation session with a player, we had a test run during which we helped the players to orient themselves with the game, its sounds, and the functions of the haptic devices. After a few minutes of that, the test itself was initiated. At various intervals of the test the evaluator would pause the game and ask the player to describe where they thought the ball was in the plane and where the paddle was (upper left, upper right, bottom left, bottom right).

6.6.3 PHANTOM/Gamepad Set-Up for Blind Users

The fist bimanual set-up consisted of the PHANTOM device which mimicked the orbit of the ball, and the Logitech gamepad which through force feedback, provided hints about the ideal position of the user's paddle in order to hit the ball, about collisions of the user's paddle with the borders of the game space and finally about successful hits of the ball with the paddle. Participants were using the PHANTOM device with their non-dominant hand and the gamepad with their dominant one.

At the beginning of the test runs, the players were not very confident in playing the game. It took them sometime to get used in handling the PHANTOM device and the Gamepad at the same time. The evaluation facilitator helped them operate the devices and explained to them what happened on the screen when they heard the various sounds. During the test run, the facilitator would activate the recording session option and then played back, in order to demonstrate the movements they made and what was their result. That seemed to help participants understand better what they needed to do. After the test run, the players became more confident and were able to create an good mental image of the game. To test whether the players had a correct mental image of the game, the facilitator periodically paused the game and asked them where they thought the ball was on the screen (upper left, upper right, lower left, lower right) and where they thought their paddle was on the screen (lower, middle, upper). According to their answers, the success rates for locating the ball and locating the paddle were calculated. Table 3 presents the ball and paddle locating scores for each user. Note that:

- S stands for Success, indicating that the user was able to locate the object requested at least four times,
- P stands for Partial success, indicating that the user was able to locate the object requested three times and
- F stands for failure, indicating that the user was able to locate the object requested less than three times

	Ball Location /Phantom	**Paddle Location/Gamepad**
User 1	S – 5 out of 6	S – 5 out of 6
User 2	S – 6 out of 6	S – 5 out of 6
User 3	F – 2 out of 6	P – 3 out of 6
User 4	P – 3 out of 6	S – 4 out of 6

Table 3 Evaluation Results for PHANTOM/Gamepad Setup for Blind Users

According to the above results the success rates for ball location and paddle location were calculated:

- Success rate for Ball location = (2 + (1*0.5))/4= 62.5%
- Success rate for Paddle location = (3 + (1*0.5))/4= 87.5%

6.6.4 BRAILLE/Gamepad Set-up for Blind Users

We used the same process of testing for the second bimanual set-up as the first one. First we had a test run with the players trying the devices, then a session was recorded and played back to show them what they did, and then the regular test was started. In this set-up, the first BRAILLE cell of the display showed the direction the paddle should move. In addition, for the position of the ball, the players had to rely on the auditory grid that produced a different sound as the ball hit each grid. To test whether the players had a correct mental image of the game, the facilitator periodically paused the game and asked them where they thought the ball was on the screen (upper left, upper right, lower left, lower right) and where they thought their paddle was on the screen (lower, middle, upper). According to their answers, the success rates for locating the ball and locating the paddle were calculated. Table 4 presents the ball and paddle locating scores for each user.

	Ball Location /Auditory Feedback	Paddle Location/Gamepad
User 1	P – 3 out of 6	S – 4 out of 6
User 2	S – 4 out of 6	P – 3 out of 6
User 3	F – 2 out of 6	S – 5 out of 6
User 4	F – 2 out of 6	P – 3 out of 6

According to the above results the success rates for ball location and paddle location were calculated:

- Success rate for Ball location = (1 + (1*0.5))/4= 37.5%
- Success rate for Paddle location = (2 + (2*0.5))/4= 75%

Table 4 Evaluation Results for BRAILLE/Gamepad Setup for Blind Users

According to the above results, it can be concluded that this bimanual interaction set-up was not as easy to follow as the PHANTOM set-up. It seemed that the auditory feedback was not enough to locate the ball on the screen, as users mentioned during the debriefing session.

In addition, it is noteworthy that the blind players had a success rate of 87.5% in locating the paddle with the Logitech gamepad in the first setup, whereas they only had a 75% success rate of locating the paddle with Logitech gamepad during the second bimanual set-up. We can make the assumption that the reason for this was that they were distracted by trying to interpret the BRAILLE and the auditory feedback at the same time.

6.6.5 Auditory Feedback/Gamepad Setup for Partially Sighted Users

The same testing process was followed for the partially sighted players as well. For this user group testing with the BRAILLE pad had no meaning, since participants could detect some movement on the screen, therefore we had them follow the auditory feedback to locate the ball and use the Logitech gamepad for the movement of the paddle.

This group of players seemed overall more confident in playing the game. This might be because of their higher experience with computers and computer games in general. However, they too had some difficulty at the beginning to follow the auditory feedback and they found the gamepad force feedback useful in guiding their paddle. During the game we asked them to change the interface to the X-Large Set-up and that seemed to raise their confidence and success rate a lot. The X-Large option enlarges the paddles and the ball 1.5 times. Two of the users said that they didn't need the auditory feedback after the enlargement. Overall, their success rate in locating the ball was pretty high and so was the success rate of locating the paddle. Table 5 presents the ball and paddle locating scores for each user.

	Ball Location /Auditory Feedback	**Paddle Location/Gamepad**
User 1	S – 5 out of 6	S – 6 out of 6
User 2	S – 4 out of 6	S – 6 out of 6
User 3	S – 6 out of 6	S – 6 out of 6
User 4	S – 4 out of 6	S – 5 out of 6

Table 5 Evaluation Results for Auditory Feedback/Gamepad Setup for Partially Sighted Users

According to the above results the success rates for ball location and paddle location were calculated:

- Success rate for Ball location = (4 + (0*0.5))/4 = 100%
- Success rate for Paddle location = (4 + (0*0.5))/4 = 100%

6.6.6 PHANTOM/Gamepad Setup for Partially Sighted Users

In this test the auditory feedback was replaced with the PHANTOM device and the interface was displayed in normal size. The players found using the PHANTOM device and the Gamepad at the same time a bit confusing at the beginning, but that confusion was completely eliminated by the end of the test run. Once they got the idea of how the PHANTOM device worked, they found it very useful. The results of the ball and paddle location are shown below in:

	Ball Location /PHANTOM	**Paddle Location/Gamepad**
User 1	S – 5 out of 6	S – 5 out of 6
User 2	S – 6out of 6	S – 6 out of 6
User 3	S – 5 out of 6	S – 6 out of 6
User 4	S – 6 out of 6	S – 5 out of 6

Table 6 Evaluation Results for PHANTOM/Gamepad Setup for Partially Sighted Users

According to the above results the success rates for ball location and paddle location were calculated:

- Success rate for Ball location = (4 + (0*0.5))/4 = 100%
- Success rate for Paddle location = (4 + (0*0.5))/4 = 100%

6.6.7 Collaborative Game Playing

After testing the players individually, we matched a blind participant with a partially sighted one to see if they could play against each other. The blind players were using the PHANTOM and the Gamepad and the partially sighted were using X-Large option and the keyboard. The participants enjoyed this part of the test a lot and it was great to notice that the partially sighted participants would help the blind ones in moving the paddle. That is something that we noticed in the previous test we did as well. In addition, the participants mentioned that they enjoyed playing against each other more than playing against the computer. This test proved that indeed two players with different levels of disabilities can play King Pong together.

6.6.8 Interviews

Apart from the success rate measurements recorded during the evaluation process, the qualitative approach of the interview was also used, for evaluating the bimanual interaction setups and the overall accessibility and usability of King Pong. After the interaction of the players with King Pong, the evaluators interviewed each child to determine their overall impressions about the game. The questions asked in the interview can be found in Appendix 6.10.3. Two evaluators took part in the interview: one conducted the interview while the other was taking notes of children's answers and questions. The interview was conducted in the form of a friendly informal discussion to encourage the children express their true feelings about the game. The questions of the interview can be found in paragraph 0 "Appendix 4C, Usability Interview Questionnaire" of the Appendixes section, while the results of the interviews are summarized in the paragraphs below.

6.6.9 Overall Satisfaction

All the children said that they enjoyed the game and answered yes in the question of whether they would like to play it again. Four of the children mentioned that they found the fact that they could change the game settings to fit their needs to be what they liked most about the game. Two children said that they liked the PHANTOM device the most about the game because it impressed them with its accuracy and how much it helped them create a mental image of the game. And the other two said that they really liked the force feedback they got from the gamepad. Six out of eight found the first bimanual set-up, the PHANTOM/Gamepad combination, to be the most effective in creating a mental image of the game and in hitting the ball, while one of the blind users found it very hard to handle the PHANTOM at the same time as the gamepad and one of the partially sighted said that he didn't need it because he could follow the auditory feedback. In the question what did you like the least about the game, three out of four blind children said that they found sometimes the auditory feedback to be overwhelming whereas one of them said that what he didn't like about the game was when he had to read the BRAILLE, listen to the auditory feedback and use the Gamepad to move the paddles all at the same time. Two of the partially sighted children said that they would have liked more levels in the game and a way to control the speed of the ball because it became too easy after awhile and thus somewhat boring. And the other two said that they didn't care for all the auditory feedback. It got annoying after awhile.

6.6.10 Learnability

In the question "Did you find it difficult to use the haptic devices? Did they help you to interact with the game?", six out of the eight children said that they found it hard at first to understand how they were supposed to handle it and what exactly it did, but they said that once they got used to it, they found it helpful in getting a mental image of where the ball was. They also mentioned that they thought the recorded sessions options during the test run helped them understand what they were supposed to do and helped them gain confidence because they could understand what they did wrong the first time.

From our previous test, we found out that it was tiring for the children to handle both devices. For that reason, in this test we moved the PHANTOM closer to the player and we placed the Gamepad on a raised platform on the desk. That way the children didn't have as much of a hard time handling the devices.

6.6.11 Accessibility

All eight children liked the fact that they could change the options to fit their needs. However, two of the sighted children said they would have liked more options such as speed, different levels etc. Three out of four blind children said that the most accessible method for them was the PHANTOM/Gamepad combination. And two of the four partially sighted children said the same thing. The other two partially sighted children said that the "X-Large" and "High Contrast" options were extremely for them because once they employed these choices they didn't really need the PHANTOM or the auditory feedback.

6.6.12 Navigation

None of the children had any serious difficulties in navigating the game's menus and accessibility options. With some help from the evaluators they were able to change their options. We did notice that in the lower menu levels there wasn't always a way to go back to the main menu and we are planning on fixing that in the next version since it created some confusion in the users.

6.7 Conclusions

To conclude, we tested eight children from ages 14-17. Four of those were blind while the other four were partially sighted. The evaluation took place in the lab at FORTH's Institute of Computer Science and it consisted of four parts.

In the first part of the evaluation we tested the players' success rate in navigating through the game's menu system. We had the users try to complete five tasks. All users managed to complete the tasks, but most required some help from the evaluators. The success rate was 60% for the blind users and 72,5% for the partially sighted users. Some of the users weren't confident in clicking around and a lot didn't know where to look for certain options. There was a lot of going back and forth the menus to find what they were looking for. In addition, certain menu levels didn't have a "Back" button and that created confusion and uncertainty. We are certain that by adding "Back" buttons in all levels and by changing a couple of menu labels to be more descriptive, the usability of the menu will improve significantly.

In the second part of the evaluation, we tested both bimanual methods. We started with the PHANTOM with the Logitech gamepad and the blind users. The success rate for ball location was 62.5% and for the paddle location 87.5%. This shows that the blind users even though at first they were having a hard time with handling the PHANTOM and the gamepad, they managed to create a mental picture for the game. It was evident that after the test run and as the game progressed, their confidence level increased. Then we introduced them to the second bimanual method the BRAILLE pad and the gamepad. Their success rate was lower when using this method. For the ball location it was 37.5% and for the paddle location it was 75%. It was important to note that even though they used the gamepad again for moving the paddle, this time they were as successful as the first time. They all mentioned that it was hard for them to follow the BRAILLE and move the paddle at the same time. On top of it the auditory feedback was overwhelming and it made them lose their concentration.

Then we tested the partially sighted users against both bimanual methods. First we tested them against the auditory feedback and the gamepad combination. As expected they had a better mental image of the game than the blind users because they could see movement on the screen. Their success rate was 100% for both the ball location and the paddle location. Two of the four partially sighted users said that the X-Large and High Contrast options were enough for them to play the game successfully even without the PHANTOM or the auditory feedback. Then we switched them to the PHANTOM device and they were also as successful as the first time around. They, too, had some hard time using it at first, but after some practice they liked it. Their success rate with this method was also 100%.

In the third part of the evaluation, we paired each blind child with a partially sighted one and have them play the game against one another. All children seemed to enjoy this part more than the single mode game. It was nice to see that just like the previous test the partially sighted users were helping the blind users in moving their paddles.

Lastly, we performed interviews with all the subjects to get their thoughts, and opinions on the game in general and the haptic devices that we used. Overall they liked the game and they thought that the haptic devices were very helpful after they learned how to use them. They didn't find using both devices at the same time as difficult as they did in the previous test and we think that's because we stabilized the gamepad on the desk and we moved the PHANTOM closer to them.

We have concluded that bimanual methods can work effectively if they are set up appropriately. The PHANTOM device was more efficient in helping the users create a mental image of the game. The auditory feedback needs some work. It seems that too much information overwhelms the user and creates confusion.

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D3: Final report of the user involvement

Executive summary

This report will give a survey over the numerous user contacts undertaken within the MICOLE project.

User contacts to explore requirements

In Work Package 1 (Users and Requirements), we undertook a series of studies in order to find preliminary requirements for the applications we were to develop in the project. Most of these contacts took place in terms of interviews carried out with members of the user organizations we located in the beginning and with whom we maintained contacts for the whole duration of the project. Following is an account of all the user contacts undertaken in this initial phase. The summary is sorted according to project partners. All contacts under the “Interviews” sections are in detail documented in Dewliverable D1.

UTA

Interviews

6 children, aged 7 to 12 years, 3 totally blind, 3 with low vision, were interviewed. The user organization contacted for these interviews was the “Parent association of visually disabled children in Finland”.
The questions posed cover these fields:

- Knowledge and learning abilities
  - Material, shape, and quantity recognition
  - Basic Mathematics
  - Reading/writing abilities
  - Computer experience
- Entertainment
  - Game types
  - General interests and hobbies

Additional contacts

Solar System and Space Application
UTA undertook several user contacts to obtain feedback for designing these two applications. 8 visually impaired or blind pupils and 13 sighted pupils were contacted.

ULINZ

Interviews

15 pupils/students were interviewed. 2 of them were studiying at the Johannes Kepler University in Linz, where they were supported by the Institute for Integrated Study at the said university. 13 of them attended the BBI – Bundes-blindenerziehungsinstitut Wien (Institute for the Education of the blind, Vienna). The two students were aged

33 and 24, both totally blind. The 13 pupils were aged 10 to 20 years, 4 of them totally blind, 4 with low vision – the remaining 5 did not specify their status of impairment.
The questions posed cover these fields:

- Knowledge and learning abilities
    - Material, shape, and quantity recognition
    - Reading/writing abilities
    - Computer experience
    - Mathematical abilities
    - Geography and orientation
- Entertainment
    - Game types
    - General interests and hobbies

Furthermore, they were asked:

- Whether they knew something at school which was accessible to everyone else, but not to them,
- Which software they would suggest to be developed in our roject, and
- Whether they would be willing to test software supplied to them by our project.

Additional contacts

None.

METZ

Interviews

Several teachers, and 6 chldren, aged from 12 to 19 years, 3 low vision, 3 blind, were interviewed.
Two questionnaires were given to the teachers. The goal of the first one was to get a list of user groups, factors/criteria and needs according teachers in general. The second one was to obtain Information about pupils and their needs for teaching.
Two questionnaires wer given to the children, too. The aim of the first one was to gather information about pupils and their needs in general, whereas the second one was to obtain information about pupils and their needs for one particular course.
In addition, interviews at a sports meeting for visually impaired children in Vittel, France, were carried out. The goals of these interviews were:

- identify needs for diagrams
- identify social behaviour at school

Additional contacts

None.

FORTH

Interviews

We interviewed 5 children, aged 5 to 12 years, of various visual condition. The children were mediated to us by the “Pan Cretan Association of Parents and Friends for Blind Children and Children with Low vision”.
The questions posed cover these fields:

- Knowledge and learning abilities
  - Material, shape, and quantity recognition
  - Basic Mathematics
  - Reading/writing abilities
  - Computer experience
- Entertainment
  - Game types
  - General interests and hobbies

Additional contacts

None.

SU

Interviews

31 pedagogues, 20 from the Vision center of Petras and 11 from the special kindergarten “Linelis” on Panevezys, were questioned.
By the questions posed, The pedagogues were invited to think how one could use computer equipment to prepare pre-school children for their education at school.

Additional contacts

None.

ULUND

Interviews

We interviewed 10 persons, aged 10 to 66 years, 5 blind, 5 low vision.
We asked them:

- Whether they knew something at school which was accessible to everyone else, but not to them,
- Which software they would suggest to be developed in our roject, and

Additional contacts

ULUND held user board meetings with the 5 members of the user board. Informal tests with the children were carried out. Also, the 5 schools attended by the ULUND user board members were visited, in order to observe actual work in the classroom.

KTH

Interviews

None carried out.

Additional contacts

Various studies with visually impaired users performed in the second project year:

- A study carried out with Six visually impaired and six sighted adults, who participated in the evaluation performed by KTH of three collaborative haptic (Phantom) applications.
- Evaluations of the auditory drag & drop application with visually impaired and sighted users.
- Evaluation of a haptic application that supports learning geometry in four schools with groups of visually impaired and sighted pupils.
- An evaluation with the aim of investigating the effects of integrating sound and haptic feedback in a virtual environment and to compare several different ways of modelling the audio feedback. The participants are visually impaired and sighted individuals, and they are not collaborating in pairs of users in this study.

User contacts in the field study on collaboration

Within Work Package 3 "Collaboration and Communication", a field study on collaborative work at school was carried out. The user contacts undertaken within this study are documented in Deliverable D8.

User contacts for final testing

AHEAD – Audio-haptic Drawing Editor And Explorer in 2D

The AHEAD application was evaluated by ULUND and KTH.

There was a total of 12 pupils and 2 teachers involved. Among the pupils, there were 3 blind, 4 low vision, and 5 sighted ones. They were aged 11 to 17 years. All pupils are integrated in mainstream education, in scholls situated in the urban areas of Sweden.

Solar System

A total of 8 pupils and no teachers was involved. Among the pupils, there were 1 blind, 3 low vision, and 4 sighted. They were 7 to 9 years of age.

The tests took place in 3 schools. Three of the tests were done in normal schools where visually impaired pupils were integrated in class with sighted pupils. One of the schools was a special school for hearing-impaired pupils.

Electrical Circuits

A total of 13 pupils and 1 teachers was involved. Among the pupils there were 3 blind an 10 low vision ones. They were aged 9 to 17 years.

The pupils come from 3 institutions:

- St Eucaire primary school (4 pupils)
- Robert Schumann secondary school (2 pupils)

- Santifontaine center (7 pupils)

All the pupils except 3 from the third school mentioned are integrated into mainstream education.

MAWEN (Mathematical Working Environment)

The MAWEN application was evaluated by ULINZ and UPMC.
There was a total of 14 pupils and 8 teachers involved.
In Austria, evaluation sessions in 2 schools took place:

- LLH (Landeslehranstalt für Hör- und Sehbildung = Municipal School for Education of Hearing and seeing), in Linz: 2 sighted teachers, 2 visually impaired pupils (low vision), aged 15 and 14 years, respectively
- BBI (Bundes-Blindenerziehungsinstitut = Federal Institute for the Education of the Blind), Vienna: 3 teachers (2 sighted, 1 blind), 7 pupils (5 blind, 2 visually impaired), aged 13 to 21 years

In France, the application was evaluated in 3 schools:

- College Buffon, Paris: 1 sighted teacher, 1 blind pupil (12 years old).
- UPI Louis Bascan, Rambouillet (Unité Pédagogique d'Intégration, a special classroom for children with disabilities integrated in a mainstream school): 1 sighted teacher, 2 blind pupils (16 years old).
- ERDV, Loos (Établissement Régional pour Déficients Visuels): 1 sighted teacher, 2 blind pupils (18 years old).

King Pong

The King Pong application was evaluated by FORTH.
A total of 4 pupils and 1 teachers were involved. Among the pupils, there were 1 blind and 3 low vision, aged 12 to 14 years.

Other user contacts

UGLAS

In March 2005, UGLAS visited the Royal National College for the Blind (RNCB) in Hereford in England. Involved in the study were 8 users, blind or with very low residual vision, of age 18 to 40 years. They were either students or staff members of the college. The goal of the study was twofold. Firstly, interviews were held with the participants either individually or in focus groups to extract information about how visually impaired people access and information in their everyday lives in work and play settings. Secondly, three of the participants were presented with a prototype application to test two-handed navigation through a computer interface (in this case using a maze). These studies are described in greater detail in D8.
In November 2005, UGLAS again visited the RNCB in Hereford in England. Two studies were conducted on this occasion with ten blind or visually impaired users taking part in the first. Four participants were members of staff and six were students. The age of these users ranged from 17 to under 50. This study examined two forms of

tactile cueing for guiding a user through a computer environment. Results showed that users were able to interpret the static cues significantly more quickly and successfully than the dynamic cues. The second study took place with nine of the ten participants in the previous study. The goal was to examine haptic trajectory playback as a method of transferring shape information to blind or visually impaired participants. The performance of these participants in recreating the shapes felt through the playback was later compared to that of a control group of sighted but blindfolded users. Results showed that it was a significantly more difficult task for the visually impaired users. This was particularly true for the two users who had been blind since birth. Both of these studies have been described in D6 in more detail.

In March 2006, UGLAS again visited the RNCB in Hereford in England. A follow up study to the trajectory playback experiment carried out in November 2005 was conducted. Ten visually impaired participants took part in the study. The age of the users ranged from 18 to under 45. Five participants from the previous study took part again (due to limited access to visually impaired participants), although with a gap of several months between the studies. The goal of the study was to examine methods of improving the performance of visually impaired users in the trajectory following task. Participants took part in two conditions; one unimodal haptic only condition similar to the haptic trajectory playback experiment described above, and one multimodal haptic and audio trajectory playback condition. A within-subject design also ensured that all participants took part in both conditions to provide a fair comparison between the conditions. Results showed that the addition of audio information significantly improved the performance of the participants in recreating the shapes. Varying the pitch of a tone was a far more successful technique for presenting information through audio than varying the audio pan. This study is described in greater detail in D7.

In June 2006, UGLAS again visited the RNCB in Hereford in England with the previous trajectory playback technique was examined in a more realistic context. A collaborative drawing environment was evaluated with three pairs of individuals. Two of the groups consisted of participants from the RNCB, and the third group consisted of one participant from the RNCB and one participant from the University of Glasgow. The RNCB participants were either students or staff at the college with the visually impaired users in this instance being adults between the ages of 20 and 44. In each case, one user was either sighted or had good residual vision, and the other was visually impaired with very little or no residual vision. The task set to participants was for the sighted user to describe an image to the visually impaired user with the visually impaired user drawing it. Results, although observational, indicated when and how the trajectory playback feature was used to describe shapes. This study is described in more detail in D9.

A pilot study has been conducted in January 2007 at UGLAS on the Electric Circuit environment constructed by METZ. wo groups of participants – one sighted and one blind in each group – took part in a study to test the potential of this environment as a collaborative learning environment. The blind participants were from the Royal National Institute for the Blind in Glasgow, and Describe Online – a group dedicated to making public areas accessible to visually impaired people. Both participants were adults and had no residual vision. Both were familiar with electric circuit diagrams. The task set to the participants was to discuss the shape and functionality of five circuits created by the experimenter. Observations from this study were made through video and audio recording. In both instances the visually impaired participant was able to navigate through and describe the shape of the circuits presented to them. With their greater expertise in circuit diagrams, they were even able to lead the discussion with the sighted user, explaining concepts such as serial and parallel circuits. These recordings were analysed with the results being collated and written up for D10.

KTH

In June 2005, KTH undertook a contact with The Swedih Handicap Institute (HI). The persons concacted were adults, with mixed status of visually impairment, and on expert user level. The objective was to get in contact with expert users that could give feedback on applications and findings from studies performed in MICOLE. The adult users participated in evaluation of the Aditory drag and drop application (D4, D9) and the Auditory haptic object localization application (D7). They then participated in studies that were reported in D4, D9 and D7.

In February 2005, KTH had a contact with the Swedish Institute for Special Needs Education, Resource Centre Vision. The users were pupils aged 7 to 16 years, both blind and low vision, in mainstream education. The contact was taken with the user organisation for two purposes. First, to get contact information to pupils that we could contact in order to ask if they would like to participate in evaluations in MICOLE. Second, to discuss shared interests regarding research that is relevant for MICOLE. These Pupils later on participated in studies that were reported in D8, D9 and D15.

SU

Beginning in November 2004, SU has been maintaining contacts with users from the Petras Avizonis Vision Centre for the whole duration of the project. The users were aged 7 to 19 years, including pupils in mainstream education together with their teachers and parents. Teachers and parents participated actively in the design of the application for the pupils. The contqacts aimed at d**efining user requirements and at the definition of users groups. They influenced the design of the** Sonification system of maps for blind people. **The contacts are documented in greater detail in D1, D2, D6, and D13.**

UPPSALA

They have been in touch several times over the years with The Swedish Institute for Special Needs Education in Stockholm for discussing our work on maps for the visually impaired and in order to get software for such maps. The latest contact was in July, 2007, where they agreed on a meeting at the institute with teachers there about the final result of our evaluation of the VTPlayer haptic mouse and the ViewPlus equipment for reading virtual maps without vision. The meeting took place after a symposium on tactile maps at the International Carthographic Conference in Moscow August 4-10, 2007, where this evaluation was reported. The meeting also included a report of the program at this symposium.

Appendices

Appendix 1.A

Interview Plan - pupil

I will make an interview, posing questions that I'd like you to answer. The answers you give are about your personal preferences and thoughts, and the questions do not have right or wrong answers. The interview will last about 20 minutes. If I pose a questions that you do not want to answer, just say so and I will skip it. You are also free to end this interview whenever you like without giving any reason to do so. The answers you give will only be seen by researchers in the project. Parents, teachers or other pupils will not be able to see your answers.

This interview is about the task in the school lesson and your opinion of it.

Background information

Age ____ Girl __ Boy __ School year ____
Integrated class ___ Special class ___

Do you ususally work in groups or pairs in school? How often?

How many are you in each group?

Can you describe the task that you worked with today?

Did you get information about the task from the teacher beforehand?
What information?

Difficulties

What was the hardest part with the task?
How was your solution?
What other hard parts were there?

What was the easiest part of the task?
How was your solution?
What other easy parts were there?

What is your opinion on the drawing function?
Were there easy parts? Which?
Were there hard parts? Which?

What is your opinion about being able to feel a drawing?
Were there easy parts? Which?
Were there hard parts? Which?

Did you use sound feedback?
For what?
How helpful did you find it to be?

Learnability

Was the training time sufficient or would you have liked to do more training before the lesson?

At what time during the lesson do you feel that the task and work flowed best? In the beginning or the end e.g.?

How long did it take you to get into the task and starting to focus on it?

Was there something that surprised you? What?

Ability to complete the task

Do you think that you had sufficient time to solve the task?

Where you able to finish the given task?

How well do you think that you managed to solve the task (1 very bad – 5 very good)?

Assistance

Would you have liked more assistance during your work?
    If yes, with what and in which way?

Co-operation

How did the cooperation work for you?
    Graded on a scale from 1-5?

What was fun with the cooperation?

What was boring with the cooperation?

How did you divide the work? Do you feel that one of you was doing the majority of the work? If yes, who and how much?

Common ground

Did you and you collaborator misunderstand each other during the task?
    If yes, when and why?
    What did you do to repair it?

Awareness

Was it possible for you to understand what your collaborator was doing? How?

Alternative methods

Have you worked with *the specific task* before? How? In group work?

How would you do this task without the AHEAD application with the PHANToM?

How well do you think that the AHEAD application worked to solve *the task* (1-5)?

How well do you think your result was with the AHEAD application compared to using normal aids (1-5)?

Would you like to use the AHEAD application for other collaborative tasks and subjects? (1 never – 5 very much)?

Would you like the AHEAD application to work in some other way? How?

Appendix 1.B

Interview Plan - teacher

I will make an interview, posing questions that I'd like you to answer. The answers you give are about your personal preferences and thoughts, and the questions do not have right or wrong answers. The interview will last about 20 minutes. If I pose a questions that you do not want to answer, just say so and I will skip it. You are also free to end this interview whenever you like without giving any reason to do so. The answers you give will only be seen by researchers in the project.

Background information

How often do the pupils usually work in groups or pairs at school?

How large are the groups normally?

Did the pupils have information beforehand of the task and the AHEAD application?

Difficulties

What was the hardest part with the task for the pupils?
    What was their solution?
What other hard parts were there?

What was the easiest part of the task for the pupils?
    What was their solution?
What other easy parts were there?

Was there something that surprised you?
    What?

Ability to complete the task

Do you think that the pupils had sufficient time to solve the task?

Where the pupils able to finish the given task?

How well do you think that the pupils managed to solve the task (1 very bad – 5 very good)?

How well do you think that the (visually impaired) pupil learned the material/method/task compared to the normal aids that are used for the task?

How well do you think that the pupil learned compared to other pupils way of learning the task?

Co-operation

How well do you think the cooperation worked?
    On a scale 1-5?

How well did it work compared to other methods you usually use?
    On a scale 1-5?

Did you see any difference in the social interaction between the pupils?

Alternative methods

Have the pupils worked with *the specific task* before?

How?

In a group?

How would the pupils and the visually impaired pupil in particular do this task without the AHEAD application with the PHANToM?

How well do you think that the AHEAD application worked to solve *the task* (1-5)?

How well do you think that the pupil's result was with the AHEAD application compared to using normal aids (1-5)?

Would you like to use the AHEAD application for other collaborative tasks and subjects? (1 never – 5 very much)?

Would you like the AHEAD application to work in some other way?

How?

Appendix 2

Interview questionnaire

First Name:
Last Name:
Age:
Sex:
Dominant hand:
Disability: blind from birth, blind or sight value
Knowledge about Braille

Pre-interview
Have you ever used a haptic device? If yes: which one?

Have you any knowledge about electric circuits?

What kind of devices and tools do you use to learn electric circuits?

Do you have special help to learn electric circuits? If yes: what kind of help?

Post-Interview
Do you agree with these sentences: 1 (don't agree) 2 3 4 (agree)

The components are hard to identify.
It is hard to explore the circuits completely.
Being constraint on the circuits helps to explore the circuits.
The guidance of the PHANToM by the mouse doesn't help to explore the circuits.
The icons on the VTPlayer help to explore the circuits.
The tactile icons are hard to recognize.
I've managed to identify all the components.
The tactile icons are more useful than the PICOB to identify the components.
The presence of the teacher help to understand more easily the circuits.
The traditional method is better than the software to learn electric circuits schematics.

Appendix 3.A - List of formulas

This appendix presents the various formulas actually used in the different evaluation sessions. In each location, these formulas were selected according to the level of the pupils. In most cases (actually each time it had been practically possible) they were provided by the teachers.

Linz, Austria (LLH) :

$3a + 4b - 6c - 9b + 7a - 12a - 4b + 7c$, $4a + 6b + (3b - 7a + 9c) - 5b + 3c - (6b + 4c)$,

$(-4r + 3s - 5t) \times (9s + 4t - r)$, $(-4x + 3y - 2z) \times (-6y + 3z - x) \times (-x + 5y + 7z)$,

$(12a - 4b + 9c) \times (-6c + a + 3b) + (-2b - 4c + 5a) \times (-a - 3b + 2c)$,

$4x^2 y - 6xy^2 z^3 + 13xy^4 z^5$, $\frac{5r^{2s} - 3rs^2 + 7r}{r^3 - 12rs^3 + r^2}$, $\frac{4a + 3b}{a^2 b^2} - \frac{-3b + 5a}{ab}$,

$\sqrt{4a^2 + 12ab + 9b^2} - \sqrt{25a^2 + 60ab + 36b^2}$

Paris, France (College Buffon)

Source: BELIN – Collection Prisme – Classe de 5ème (provided by the teacher).

$(12 - 7) * (12 + 7)$, $26 - \frac{16}{2}$, $A = 36 * (12 + 4)$,

$B = 36 + (12 * 4)$, $(9 + 4) * (6 + 2)$, $[9 - (2 + 6)] * 2$

Rambouillet, France (UPI Louis Bascan)

Source: Mathematics schoolbook - Classe de 2de (provided by the teacher.)

$A = \frac{2x^2 - 3x + 1}{x + 2}$, $a = \frac{3^3 * 5^2}{3^2 * 5^4}$, $A = \frac{15 + x}{3 - x}$, $B = \frac{-2^2 + 2 * (1 - 3)^2}{(2\sqrt{2})^2}$,

$C = \frac{-2}{\frac{2}{3} - \frac{3}{2}}$

Loos, France (Établissement Régional pour Déficients Visuels)

Source: Collection Terracher – Math – Enseignement de spécialité – Terminale S (and in addition the first two samples from UPI Louis Bascan, because some of the pupils were having a similar degree in mathematics).

$$A=\frac{2x^2-3x+1}{x+2}, \qquad B=\frac{-2^2+2*(1-3)^2}{\left(2\sqrt{2}\right)^2}, \qquad f(x)=\frac{\ln x}{\sqrt{x}}, \qquad \frac{t^2}{1+t}=t-1+\frac{1}{1+t}$$

$$g'(x)=\frac{1}{2x\sqrt{x}}\left[\ln x+2\left(x\sqrt{x}-1\right)\right], \qquad f(k+1)\le\int_k^{k+1}f(t)dt\le f(k)$$

Appendix 3.B - Raw results

Naming and numbering conventions

The 14 pupils are named P1 to P14, the 8 teachers T1 to T8, according to the details presented in section 5.4.2 “Context” above. Since the first 3 teachers from the LLH Linz, T1 to T3, were testing both the navigation and the manipulation component of the system, but were interviewed separately on them, their voices with respect to the two components are distinguished by a naming convention such as “T1-m” for the voice of T1 in the manipulation component, and “T1-n” for his/her voice when testing the navigation part, and so on.

Part 1. Navigation and Synchronisation: Pupils' questionnaire

Question 1: Math software currently used

1. With which software do you currently work in Mathematics?

Linz

Question	P4	P5	P6	P7	P8	P9
1	Excel	MuPADPro	MuPAD	Windows Editor (NotePad)	Microsoft Word	Microsoft Word

Paris

Question	P10	P11	P12	P13	P14
1	ReadMath (with IRIS[1])	None [2]	ReadMath (with IRIS)	ReadMath (with IRIS)	ReadMath (with IRIS)

(1) *EuroBraille IRIS is a Braille notebook, including a basic Maths software called ReadMath*

(2) *I was working the last year with a Perkins for Maths. This year I am working with a computer with a speech synthesis and I am waiting to be able to use a computer with ReadMath (with IRIS)*

Questions 2-5: Math software for the blind

2. Do you use software designed especially for the education of blind pupils in Mathematics? (yes/no)
3. Did you ever consider to use such software? (yes/no)
4. If yes, which one?
5. If yes, how satisfied were you with that software? (Marks: 1 = very much satisfied, 5 = not at all satisfied)

Linz

Question	P4	P5	P6	P7	P8	P9
2	Yes	No	No	No	No	No
3	No	No	No	Yes	No	No
4	n.a.	n.a.	n.a.	Tabular rep.	n.a.	n.a.

Question	P4	P5	P6	P7	P8	P9
				of formulas		
5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Paris

Question	P10	P11	P12	P13	P14
2	Yes (ReadMath)	No	Yes (ReadMath)	Yes (ReadMath)	Yes (ReadMath)
3	No	Yes but it's complicated	Yes (ReadMath)	No	No
4	n.a	n.a	n.a	n.a	n.a
5	3	4	2	1	1

Question 6: Getting Acquainted with our Software

6. How easy, or how difficult, was it for you to get acquainted with our software? (Marks: 1 = very easy, 5 = very difficult)

Linz

Question	P4	P5	P6	P7	P8	P9
6	3	2	2	1	3	1

Paris

Question	P10	P11	P12	P13	P14
6	2	5	3	3	3

Questions 7-8: Keyboard Commands

7. How do you assess the keyboard shortcuts chosen by us? (Marks: 1 = very well designed, 5 = very badly designed)
8. Which changes to the keyboard shortcuts would you suggest?

Linz

Question	P4	P5	P6	P7	P8	P9
7	1	1	2	2	2	1
8	n.a.	n.a.	see 8-P6	see 8-P7	see 8-P8	n.a.

8-P6: *Reassign STRG-F5 to F9*
8-P7: *Use F1/F2 for CollapseAll/ExpandAll, F3/F4 for CollapseSelection/ExpandSelection, F5 for Help*
8-P8: *Use function keys which are simpler to learn, or keys on the Braille display*

Paris

Question	P10	P11	P12	P13	P14
7	1	1	1	1	2

Question	P10	P11	P12	P13	P14
8	n.a.	n.a.	n.a.	n.a.	n.a.

Question 9: Simplification of Work by our Software

9. Do you think you understood the formulas with our software easier than with the methods you used until now? (Marks: 1 = it was much easier, 2 = it was somewhat easier, 3 = it was as cumbersome as usual, 4 = it was even more cumbersome than usual, 5 = it was much more cumbersome than usual)

Linz

Question	P4	P5	P6	P7	P8	P9
9	1	3	3	2	3	2

Paris

Question	P10	P11	P12	P13	P14
9	2	1	1	3	3

Questions 10-11: Synchronisation

10. Did you get the impression that the synchronisation between Braille and visual representation was working? (Marks: 1 = worked very well, 5 = worked very badly)
11. Do you feel that through synchronisation you can easier communicate with your teacher? (Marks: 1 = absolutely, 5 = noticed no difference)

Linz

Question	P4	P5	P6	P7	P8	P9
10	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
11	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Paris

Question	P10	P11	P12	P13	P14
10	1	4	5	3	2
11	5	1	1	1	1

Questions 12-13: Software Speed

12. How do you assess the speed of the system? (Marks: 1 = very fast, 5 = very slow)
13. Do you deem the speed of the system sufficient? (Marks: 1 = completely sufficient, 5 = not at all sufficient)

Linz

Question	P4	P5	P6	P7	P8	P9

Question	P4	P5	P6	P7	P8	P9
12	1	3	3	2	4	2
13	3	5	1	2	2	3

Paris

Question	P10	P11	P12	P13	P14
12	3	3	5	2	2
13	3	2	4	2	2

Question 14: Overall Helpfulness of the Software

14. Do you find the software helpful for your education altogether? (Marks: 1 = very helpful, 5 = not at all helpful)

Linz

Question	P4	P5	P6	P7	P8	P9
14	1	1	2	1	2	1

Paris

Question	P10	P10	P10	P10	P10
14	3	1	1	1	1

Question 15: Comments of the Pupils

15. Which changes, improvements, or extensions of the software would you desire? (for every item you claim, please indicate how important it is for you: 1 = very important, 2 = moderately important, 3 = not so important)

Linz

Question	P4	P5	P6	P7	P8	P9
15	n.a.					n.a.
Increase speed		2	1	2	2	
Other		Increase speed (1)		Change keyb. commands (3)		

Paris

Question	P10	P11	P12	P13	P14
15				n.a.	n.a.
Increase speed	1				
Other		Enable editing (1)	Improve synchro (1)		

Part 1. Navigation and Synchronisation: Teachers' questionnaire

Question 1: Math software currently used

1. Which software do you currently use in your maths teaching?

Linz

Question	T1-n	T2-n	T3-n	T4-n	T5-n
1	MS Word, MS Excel	MS Word, MuPAD, MS Excel	Excel, MuPAD	No software	MS Office

Paris

Question	T6	T7	T8
1	ReadMath (with IRIS)	ReadMath (with IRIS)	ReadMath (with IRIS)

Questions 2-5: Math Software for the Blind

2. Do you use software that is designed especially for the education of blind pupils in Mathematics? (yes/no)
3. Did you sometimes consider to employ such software? (yes/no)
4. If yes, which one?
5. If yes, how satisfied were you with that software? (Marks: 1 = very much satisfied, 5 = not at all satisfied)

Linz

Question	T1-n	T2-n	T3-n	T4-n	T5-n
2	No	No	No	Yes	No
3	No	No	Yes	Yes	Yes
4	n.a.	LaTeX	Lambda	MuPAD	MuPAD
5	n.a.	n.a.	3	2	n.a.

Paris

Question	T6	T7	T8
2	Yes	Yes	Yes
3	Yes	Yes	Yes
4	n.a.	n.a.	n.a.
5	4	1	3

Question 6: Getting Acquainted with our Software

6. How easy, or how difficult, was it for you to get acquainted with our software? (Marks: 1 = very easy, 5 = very difficult)

Linz

Question	T1-n	T2-n	T3-n	T4-n	T5-n
6	2	n.a.	2	2	1

Paris

Question	T6	T7	T8
6	5[1]	1	2

(1) *because it isn't finalised*

Questions 7-8: Keyboard Commands

7. How do you assess the keyboard combinations assigned by us? (Marks: 1 = very well designed, 5 = very badly designed)
8. In which respect would you change/improve the keyboard shortcuts?

Linz

Question	T1-n	T2-n	T3-n	T4-n	T5-n
7	2	n.a.	2	2	1
8	n.a.	n.a.	see 8-T3-n	see 8-T4-n	n.a.

8-T3-n: *If possible, take the conditions of laptop keyboards more into account*

8-T4-n: *If possible, design conformant to standard, e.g., shift-right to extend selection*

Paris

Question	T6	T7	T8
7	1	1	2
8	n.a.	n.a.	n.a.

Questions 9-10: Simplification of Work by our Software

9. Do you think that our software may support a blind pupil in understanding mathematical expressions? (Marks: 1 = absolutely, 5 = absolutely not)
10. Did you notice an improvement in your pupils' understanding of mathematical expressions compared to their traditional work during the tests? (Marks: 1 = marked improvement, 2 = partial improvement, 3 neither improvement nor complication, 4 = partial complication, 5 = marked complication)

Linz

Question	T1-n	T2-n	T3-n	T4-n	T5-n
9	3	1	2	n.a.	1
10	n.a.	3	n.a.	n.a.	n.a.

Paris

Question	T6	T7	T8
9	1	1	Between 2 and 3

Question	T6	T7	T8
10	5	2, because the time of the evaluation is very short	2

Questions 11-12: Synchronisation

11. Did you get the impression that the synchronisation between Braille and visual representation did work? (Marks: 1 = it worked very well, 5 = it worked very badly)
12. Did you find the synchronisation helpful for your teaching? (Marks: 1 = very helpful, 5 = not at all helpful)

Linz

Question	T1-n	T2-n	T3-n	T4-n	T5-n
11	n.a.	1	1	2	1
12	n.a.	5	4	1	1

Paris

Question	T6	T7	T8
11	1	4	2
12	3	1	1

Questions 13-14: Software Speed

13. How do you assess the speed of the system? (Marks: 1 = very fast, 5 = very slow)
14. Do you deem the speed of the system sufficient? (Marks: 1 = completely sufficient, 5 = not at all sufficient)

Linz

Question	T1-n	T2-n	T3-n	T4-n	T5-n
13	3	3	2	3	5
14	3	n.a.	1	3	5

Paris

Question	T6	T7	T8
13	5	3	Between 2 and 3
14	5	3	Between 2 and 3

Question 15: Overall Helpfulness of the Software

15. Do you find the software helpful for your teaching altogether? (Marks: 1 = very helpful, 5 = not at all helpful)

Linz

Question	T1-n	T2-n	T3-n	T4-n	T5-n
15	3	5	4	5	1

Paris

Question	T6	T7	T8
15	3	1	2

Question 16: Comments of the Teachers

16. Which changes, improvements, or extensions of the software would you desire? (Please assign a priority to each of the items claimed by you: 1 = high, 2 = medium, 3 = low priority).

Linz

16-T1-n: *Simplification of usage: Medium priority*

16-T8-n: *In an integrated setting, exercises given by the sighted teacher should be automatically converted into linear form, such that extra work is eliminated.*

16-T3-n: *Provide for input of expressions: High priority. Make possible export and import to various formats: Medium priority*

16-T4-n: *Support calculations: High priority. Fix errors in synchronisation, especially selection: High priority. Increase speed: High priority. Design keyboard commands according to standard: Medium priority*

16-T5-n: n.a.

Paris

16-T6-n: *Increase speed (Priority 1);*
It should allowed the pupil to an exercise from the schoolbook (Priority 1);
Integrated calculator (Priority 1);
A possibility to support also the education in geometrics (Priority 1).

16-T7-n: *The pupils should be allowed to type themselves a mathematical text (Priority 1);*
The marked part of the formula by the teacher should correspond with the part which is marked on the Braille display and vice-versa (Priority 2);
A possibility to learn the most complicated formulas in much more steps (Priority 3).

16-T8-n: *A possibility to insert a mathematical expression at the place of a bloc from the initial expression. (Priority 1)*

Part 2. Manipulations: Pupils' questionnaire

Question 1: Math software currently used

16. With which software do you currently work in Mathematics?

Linz

Question	P1	P2	P3
1	Excel	MuPAD	MuPAD

Questions 2-5: Math software for the blind

2. Do you use software designed especially for the education of blind pupils in Mathematics? (yes/no)
3. Did you ever consider to use such software? (yes/no)
4. If yes, which one?
5. If yes, how satisfied were you with that software? (Marks: 1 = very much satisfied, 5 = not at all satisfied)

Linz

Question	P1	P2	P3
2	No	No	No
3	No	No	No
4	n.a.	n.a.	n.a.
5	n.a.	n.a.	n.a.

Question 6: Getting Acquainted with our Software

6. How easy, or how difficult, was it for you to get acquainted with our software? (Marks: 1 = very easy, 5 = very difficult)

Linz

Question	P1	P2	P3
6	2	2	2

Questions 7-8: Keyboard Commands

7. How do you assess the keyboard shortcuts chosen by us? (Marks: 1 = very well designed, 5 = very badly designed)
8. Which changes to the keyboard shortcuts would you suggest?

Linz

Question	P1	P2	P3
7	1	1	3
8	They are OK	They are OK	Assign the function keys according to a logical scheme

Question 9: Simplification of Work by our Software

9. Do you feel that calculating was easier for you with our program than with the methods you used until now? (Marks: 1 = it was much easier, 2 = it was somewhat easier, 3 = it was as cumbersome as usual, 4 = it was even more cumbersome than usual, 5 = it was much more cumbersome than usual)

Linz

Question	P1	P2	P3
9	2	2	2

Questions 10-11: Software Speed

10. How do you assess the speed of the system? (Marks: 1 = very fast, 5 = very slow)
11. Do you deem the speed of the system sufficient? (Marks: 1 = completely sufficient, 5 = not at all sufficient)

Linz

Question	P1	P2	P3
10	2	1	1
11	1	1	1

Questions 12-13: Quality of Support Granted by the Software

12. Do you think that the program takes away too much computational work from you? (Marks: 1 = absolutely, 5 = not at all)
13. Do you feel to be patronized by the program, such that you would like to do calculations in a way different from the one dictated by the software? (Marks: 1 = not at all, 5 = absolutely)

Linz

Question	P1	P2	P3
12	2	5	1
13	5	1	2

Question 14: Overall Helpfulness of the Software

14. Do you find the software helpful for your education altogether? (Marks: 1 = very helpful, 5 = not at all helpful)

Linz

Question	P1	P2	P3
14	2	2	5

Question 15: Comments of the Pupils

15. Which changes, improvements, or extensions of the software would you desire? (for every item you claim, please indicate how important it is for you: 1 = very important, 2 = moderately important, 3 = not so important)

Linz

Question	P1	P2	P3
15	n.a.	n.a.	n.a.

Part 2. Manipulations: Teachers' questionnaire

Question 1: Math Software Currently Used

1. Which software do you currently use in your maths teaching?

Linz

Question	T1-m	T2-m	T3-m
1	MS Word, MS Excel	MS Word, MuPAD, MS Excel	MS Excel, MuPAD

Questions 2-5: Math Software for the Blind

2. Do you use software that is designed especially for the education of blind pupils in Mathematics? (yes/no)
3. Did you sometimes consider to employ such software? (yes/no)
4. If yes, which one?
5. If yes, how satisfied were you with that software? (Marks: 1 = very much satisfied, 5 = not at all satisfied)

Linz

Question	T1-m	T2-m	T3-m
2	No	No	No
3	No	No	Yes
4	n.a.	n.a.	Lambda
5	n.a.	n.a.	3

Question 6: Getting Acquainted with our Software

6. How easy, or how difficult, was it for you to get acquainted with our software? (Marks: 1 = very easy, 5 = very difficult)

Linz

Question	T1-m	T2-m	T3-m
6	3	3	2

Questions 7-8: Keyboard Commands

7. How do you assess the keyboard combinations assigned by us? (Marks: 1 = very well designed, 5 = very badly designed)
8. In which respect would you change/improve the keyboard shortcuts?

Linz

Question	T1-m	T2-m	T3-m
7	2	n.a.	2
8	n.a.	n.a.	If possible, take conditions of laptop keyboards more into account

Questions 9-10: Simplification of Work by our Software

9. Do you think that our software may support a blind pupil in performing calculations? (Marks: 1 = absolutely, 5 = absolutely not)
10. Did you notice during the tests that your pupils could do mathematical calculations easier compared to their traditional way of working? (Marks: 1 = marked improvement, 2 = partial improvement, 3 neither improvement nor complication, 4 = partial complication, 5 = marked complication)

Linz

Question	T1-m	T2-m	T3-m
9	3	3	2
10	n.a.	3	n.a.

Questions 11-12: Software Speed

11. How do you assess the speed of the system? (Marks: 1 = very fast, 5 = very slow)
12. Do you deem the speed of the system sufficient? (Marks: 1 = completely sufficient, 5 = not at all sufficient)

Linz

Question	T1-m	T2-m	T3-m
11	2	3	1
12	2	n.a.	1

Question 13: Quality of Support Granted by the Software

13. Did you feel that the software would take too much computational work away from the pupil, or that it even would conceal understanding of mathematical concepts? (Marks: 1 = not at all, 5 = absolutely)

Linz

Question	T1-m	T2-m	T3-m
13	3	n.a.	1

Question 14: Overall Helpfulness of the Software

14. Do you find the software helpful for your teaching altogether? (Marks: 1 = very helpful, 5 = not at all helpful)

Linz

Question	T1-m	T2-m	T3-m
14	4	5	3

Question 15: Comments of the Teachers

15. Which changes, improvements, or extensions of the software would you desire? (Please assign a priority to each of the items claimed by you: 1 = high, 2 = medium, 3 = low priority).

Linz

15-T1-m: *n.a.*

15-T2-m: *In an integrated setting, exercises given to the pupil by the sighted teacher should be automatically converted into linear form, such that extra work would be eliminated (priority 1).*

15-T3-m: *Nature and intensity of support should be configurable (priority 1).*
Division should be supported (priority 1).

Appendix 4A, Consent Form

Parent/Guardian Consent Form

Purpose of this research
The purpose of this research is to evaluate the usability and accessibility of the King Pong software game in respect to blind children or children with visual impairments. Your child's participation is considered important and may serve to improve the usability and accessibility of King Pong. The purpose of this form is to ask your consent for your child to participate in the usability evaluation of the King Pong software game and to be video recorded. Video recording will be used for further analyzing the data that will be collected during this evaluation session. Video recording will only be used in the terms of this usability evaluation and will not be published or used for any other reasons.

Permission to participate
I the undersigned represent and warrant that I am the parent or legal guardian of the child named below, I am at least 18 years of age, and possess the legal right to enter into this agreement. I hereby consent for my child/ward to participate in the usability evaluation of "King Pong" software and be video recorded for the purpose mentioned above and according to the aforementioned terms.

Youth's name:	
Parent/Guardian:	
Signature:	
Date:	

Appendix 4B, Background Information Questionnaire

The main goal of the following questionnaire is to help us in evaluating the King Pong game application. The information gathered will be used exclusively for the usability and accessibility evaluation of this application and will not be shared with any third party or used for any other purposes.

1. Age ______________

2. Gender

- ☐ Male
- ☐ Female

3. Education

Please select your level of education

- ☐ Elementary School
- ☐ Middle School
- ☐ High School
- ☐ Technological Education Institute
- ☐ University Education
- ☐ Other:____

4. Frequency of computer use

How often do you use the computer? Please select one of the following options:

- ☐ Less than twice per month
- ☐ Twice per month
- ☐ Once or twice per week
- ☐ Three or four times per week
- ☐ Five or six times per week
- ☐ Every day

5. Purpose of computer usage

What do you use the computer for? Please choose all that apply:

- ☐ Writing
- ☐ Reading and Sending E-mails
- ☐ Web browsing
- ☐ Other:____

____

____

____

6. Computer skills level

What do you think is your computer skill level? Please select one of the following:

- ☐ Very good
- ☐ Good
- ☐ Bad
- ☐ Very bad

Appendix 4C, Usability Interview Questionnaire

1. Did you find the game enjoyable? Do you want to play it again?

2. What did you like most about the game?

3. What did you like least about the game?

4. Was there anything that you did not understand?

5. Did you find difficult to use the haptic devices? Did they help you to interact with the game?

6. Did you find the bimanual interaction helpful? Did you obtain a more clear mental image of the game?

7. Did the auditory environment of King Pong help you to locate the position and direction of game objects?

8. How much time did you need to familiarize yourself with the auditory and haptic display of the game?

9. Did the reproducible game sessions help you to familiarize yourself with the auditory and haptic display of the game?

10. Is there any feature that you would like to see in the game?

11. Were the two-player games more enjoyable than the single-player?

12. Did you manage to cooperate with the partner effectively?

Appendix 4D, Initial Evaluation

In this study, the usability and accessibility of King Pong is evaluated in a collaborative environment. The evaluation process encompasses two main phases. In the first phase, a group of HCI experts interacted with the game trying to detect common design flaws and proposed relative solutions in the context of a heuristic evaluation. This evaluation method is known as expert-based inspection and aim at eliminating the clumsy design errors in order not to frustrate the real subjects with them during user trials. In the second phase, four blind and partially sighted children invited to participate to a preliminary test. In addition, able-bodied children using screening techniques to simulate physical impairments collaborated with visually impaired to investigate whether the King Pong can effectively support game sessions between players with different disabilities.

Evaluation Summary

The overall purpose of the evaluation was twofold: to evaluate the usability and accessibility of menus and to assess how effectively information is conveyed to disabled people comparing also the different bimanual interfaces. In particular, subjects were asked to navigate through menus following specific scenarios (or tasks). As far as the second goal is concerned, the *thinking aloud* (Nielsen, 1993) approach was chosen as the most appropriate for evaluating a game. According to this approach, one evaluator was observing the players interacting with the game while he asked them for vocalization of their thoughts and feelings about the gameplay experience. This test revealed if players had obtained a correct mental image of the game space and how confident they had been about playing it effortlessly. More importantly, this method enabled designers to identify players' major misconceptions.

Participants

One blind and three partially blind children took part in the evaluation while they were also separated into two groups. The age of the children was ranged between 12 and 14 year old while they had not any additional disability. Furthermore, all children were frequent computer users whereas they had limited experience in PHANTOM haptic device. The subjects' characteristics are summarized in the following table.

	Group 1		Group 2	
Sight	Blind	Low vision	Low vision	Low vision
Age	14	12	12	13
Gender	M	F	M	F
Relationship	Schoolmates		Schoolmates	
Other disability				
Hand dominance	Right-handed	Right-handed	Left-handed	Right-handed
Previous experience of Phantom device	Yes	No	No	No
Computer use	frequently	frequently	frequently	frequently

Table 7: Subject's characteristics

Context

During the first two weeks of June 2007 (1 - 15) an experimental evaluation conducted by FORTH examining the usability and accessibility level of King Pong. The evaluation took place during the afternoon hours after school. The system installed at the usability evaluation laboratory of FORTH equipped with all necessary apparatus (computers, recording equipment, etc.). The King Pong set up comprised of a computer with keyboard and mouse, a 17" LCD display, the auditory grid, an Omni PHANTOM device and a vibration controller (Logitech gamepad). At the time of assessment only the evaluators and the subjects were present in the evaluation laboratory. Moreover, the partially sighted children wore blindfolds when a task required not to use their vision.

Procedure and tasks

Firstly, HCI experts tried to create a friendly atmosphere so that children not to hesitate to ask any question or get embarrassed if they did not manage to complete a task. Subsequently, they gave a brief description of the Pong game and of its rules to children; although the children urged that they were already aware of them. After that, the children were asked to fill in a questionnaire about their computer use in order that evaluators could determine children's familiarization with computers and haptic or game devices. The results of this survey indicated that all subjects were frequent computer users, but novice computer game players. Furthermore, the survey also unveiled that the children had limited experience in game controllers and haptic devices. In particular, they stated that they had never used any kind of game controller like joystick, gamepad, etc. Additionally, the blind child reported that he had used the PHANTOM device only twice in the past while the other three did not have any experience at all. For that reason, the evaluators decided to introduce a training session before evaluation started so that children got familiarized with the gamepad and PHANTOM device. It was decided that the "Frictionless Sphere", "Frictionless Plane" and "Hello Sphere" examples from Sensable were the most suitable demos to train children handling the PHANTOM device. This training session lasted about half an hour for all children while at the end they were pretty excited with the capabilities of this device as they stressed the quality of feedback they perceived. Afterwards, another training session followed which lasted only few minutes concerning the vibration game controller. In that session, evaluators explained how the gamepad works and how it should be held as well as they show some demonstrating the vibration of it.

The first phase of the evaluation was dedicated to the assessment of usability and accessibility of menus. To that end, the children were asked to complete the following tasks:

- Enlarge the size of game objects (ball and paddles) selecting the "X-Large" option through menu.
- Select a two-player game.
- Select your dominant hand.
- Quit game.

In the second phase of the evaluation, the objective was to assess how effectively information is perceived by disabled people testing also the different bimanual interfaces. The first bimanual interface consists of a PHANTOM device and a vibration controller while the second one includes a Braille Display and a vibration controller. These two interactions have been reported in deliverable D5. In the beginning of the evaluation in order that children got familiarized with the innovative set up, they were provided some hints about the direction that should move the paddle. These hints were conveyed through force feedback effects and speech messages. Once evaluators deemed that children were confident enough to play the game, the main evaluation began which comprised of two parts. In the first part, each child interacted with King Pong using the two bimanual interfaces. As reported in a previous section, the four children were separated into two groups. One group played the game using the first bimanual interface and the second one afterwards while the other group employed the interfaces in the reverse order. The rationale behind this arrangement is that evaluators wanted to investigate the impact of each interface without introducing bias. In the second part, children played two-player games as opposed to the first part in which they played against the computer opponent. In this part, evaluators assessed the ability of King Pong to offer enjoyable two-player sessions between people with different disabilities, as for instance between visually and motor impaired children. Additionally, the evaluators paused the game and asked the subjects frequently about the position (upper right, upper left, lower right, lower left) of game objects in order to assure that their mental model of game space matched the real one. Finally, after the end of evaluation, subjects were asked to fill in an overall satisfaction questionnaire.

Interviews

After the interaction with King Pong, evaluators interviewed children to determine their satisfaction from the game. The interview was based on as well as on the IBM Computer Usability Satisfaction Questionnaires. Two evaluators took part in the interview: the first one conducted the interview while the second one was taking notes of children’s answers and comments. Evaluators tried to conduct the interview in the context of a friendly discussion. The following questions were asked to the subjects:

- Did you find the game enjoyable? Do you want to play it again?
- What did you like most about the game?
- What did you like least about the game?
- Was there anything that you did not understand?
- Did you find difficult to use the haptic devices? Did they help you to interact with the game?
- Did you find the bimanual interaction helpful? Did you obtain a more clear mental image of the game?
- Did the auditory environment of King Pong help you to locate the position and direction of game objects?
- How much time did you need to familiarize yourself with the concept of the game?
- Did the reproducible game sessions help you to familiarize yourself with the auditory and haptic display of the game?
- Is there any feature that you would like to see in the game?

- Were the two-player games more enjoyable than the single-player?
- Did you manage to cooperate with your partner effectively?

Measurements

The overall evaluation process was recorded by the recording equipment of the evaluation laboratory. Additionally, one evaluator was responsible for taking photographs, trying not to distract the children.
The King Pong has a built-in functionality which allows for logging of game sessions and reproduction of them. All game sessions during the evaluation were logged so that evaluators could have the opportunity to analyze and investigate them at a later time.

Results

General usability

The subjects did not experience any major difficulty during the evaluation, given that the concept of the interaction was totally new to them and especially the haptic devices and the auditory environment. In fact, they seemed to need some time in order to get used these novel features of the game. Nonetheless, the blind child faced greater difficulties in the beginning of the evaluation since he did not feel comfortable using the bimanual interfaces and appeared confused from the information he perceived. More importantly, he complained that he could not handle both devices simultaneously. Similarly, the other children also pointed out that it was tiring to manipulate both devices at the same time. After these comments, evaluators rearranged the equipment so that PHANTOM device was closer to children. In addition, the subjects complained that it is not comfortable to handle the vibration gamepad with only one hand. For this reason, evaluators placed the gamepad on a stand to facilitate players to interact with this device. Children responded positively to these two changes as they were much more confident of playing the King Pong after these modifications.

As reported, the children formed two groups to evaluate the two different bimanual interfaces. The test revealed that the bimanual interface consisting of the PHANTOM device and the vibration gamepad, provides players with more valuable information than the other bimanual interface. Particularly, the group of children which used this interface first appeared to be more effective in playing the game and locating the position of game objects. This is mostly attributed to the high quality of feedback that PHANTOM device delivers. In contrast, the group of players which used the interface comprised of a Braille display and the vibration gamepad, did not manage to complete the tasks as effectively as their peers of the first group. Moreover, the game was evaluated against the left-handed child to ensure that both right-handed and left-handed players are able to interact equally with the specific haptic devices.

The three partially sighted children found quite helpful the option “x-large” that the game offers. Using this option the game objects or sprites (ball and paddles) are displayed enlarged by a factor of 1.5. This game feature allowed children to use their partial vision to familiarize themselves with the game elements very quickly. Indicative is the fact that the partially sighted children were much more confident after several minutes of interacting with the game, as opposed to the blind child. Afterwards, these children were asked to play the game without using their partial vision so that evaluators could ascertain the impact of exploiting the visual modality. The results of this test indicated that children were able to play the game without facing problems. This implies that King Pong does require a short time for training.

An important aspect of King Pong is the recording and playback functions which were proved to be very helpful for children. These features allow for recording a game session and in a later time to precisely reproduce it. It must be noticed that during a reproduction of a game session the auditory environment and the haptic devices are. The children were impressed when they could feel the movements of the paddle that they had done some minutes before. In particular, they understood the wrong decisions about that they move and this was a significant boost to the training phase of King Pong.

King Pong offers an intelligent computer opponent in order to arouse the interest of players for the game. The intelligent opponent changes its behavior according to the progress of the game and thus it acts as a stimulus for players to explore new characteristics of the computer opponent. The subjects asked about this feature since they had not understood this concept in the first place. Moreover, they became more and more excited about this feature and they attempted to make the computer opponent angry trying to win him a number of consecutive times.

As far as the stability of the game is concerned, users did not experience any unexpected event or crash.

Exploration and navigation

The exploration of the game space of King Pong was quite well after an initial training session. During the assessment, the evaluators were pausing the game frequently to ask the subjects about the position and direction of the paddle and ball. As the children's experience was getting longer, the wrong answers to these questions were lessening.

Moreover, the evaluation was also concentrated on the usability of menu options. In this task, the children managed to navigate through the menus without problems. More importantly, the partially sighted subjects were asked not to use their vision since evaluators deemed that this task was rather easy to be accomplished.

Learnability

The results of the evaluation indicated that the King Pong has a quite fast learning curve. This means that the children get familiarized with the game gradually. In the beginning, children experienced several difficulties in locating the position and direction of the ball and mainly the position of the paddle that they controlled. However, the majority of the children appeared to be confident of playing the game fairly quickly. This happened for mainly two reasons: First, due to sophisticated haptic devices that are used, it took children some time to get familiarized with them. Nevertheless, once children got used to these device, they seemed to perceive a quite clear mental image of the game. Second, the inexperience of the children in computer games may account for these difficulties that children faced in the beginning.

Assistance

Evaluators were continuously helping the children during the experiment. The subjects were frequently asking for confirmation and reminding of the tasks that they had to complete. In particular, the blind child appeared to feel more the need to ask for help. Additionally, three children asked about the role of PHANTOM device and what kind of information they were supposed to perceive from this device. However, as the children were getting familiarized with the game, the number of questions was gradually reduced. More importantly, the children assist each other in two-player games. For instance, the first player in which direction should move the paddle.

Ability to complete the task

All children managed to complete all the tasks which were assigned to them. However, the blind children proved to have several difficulties at the beginning of the testing but after some minutes he understood the concept of the game.

Evaluation issues of co-operation

In the second part of the evaluation, the evaluators organized two-player game sessions. In this part, the visually impaired children played against each other while able-bodied players using screening techniques to simulate physical impairments and more specifically the absence of the upper limbs played against the partially sighted children. The aim of this test is to investigate if impaired users, even with different types of disabilities, can cooperate effectively and effortlessly in the context of a two-player King Pong game.

Having the experience of single-player games, all subjects did not face any noteworthy difficulty. Interesting was, though, the fact that visually impaired players were prompting each other to which direction to move the paddle that they controlled in order to hit the ball. Furthermore, the evaluators noticed that the children enjoyed more the game when played against each other rather than against the computer opponent. Finally, the visually impaired children played against subjects simulating physical impairments. This test indicated that King Pong can potentially accommodate two-player games between motor impaired and visually impaired players.

Discussion and conclusions

In this study, the King Pong game has been tested in a collaborative environment. The participants of the evaluation were four visually impaired children aged between 12 and 14 years old. The user-based evaluation included two main phases. In the first one the children played against the computerized opponent. This phase was considered to introduce the participants to the novel concept of King Pong game. The second phase emphasized the collaborative aspect of the game. For this reason the children were asked to form two groups and played two-player games so that evaluators were able to investigate the collaborative potential of the game.

In the beginning, the participants made several complaints about the ergonomics and faced some difficulties in understanding the set-up of the game and the information that they were supposed to perceive from the auditory display. This can be partially attributed to the fact that all children had limited experience in haptic devices. The evaluators responded to these notes by changing the arrangement of the devices while trying also to explain them the overall concept of the game. However, after this initial training session, the children were able to interact with the game having only minor difficulties. More importantly, in two-player games the evaluators observed that the children enjoyed the game and the collaboration between them was quite effective.

As it turns out, some further investigation should be conducted into facilitating the familiarization of novice players with the game. For instance, an effective way to boost this process would be to add a built-in training session intended to beginners in which novice users will familiarize themselves with the auditory environment and the haptic devices.