

ProbonoWorld: Educating the Mentally Handicapped in a Virtual Environment using Props on a Board

Saskia Groenewegen¹, Stefanie Heinz¹, Anke Huckauf¹ and Bernd Fröhlich¹

¹Faculty of Media, Bauhaus-Universität Weimar, Germany

Abstract

ProbonoWorld is a system that allows mentally handicapped persons to safely train real-world situations in a virtual learning environment. Our system is based on the idea of using a prop on a board as an intuitive input device. ProbonoWorld is an expandable virtual world which may include different tasks at several locations and even tasks spanning multiple locations, such as shopping at the supermarket and then preparing a meal at home. To enable navigation through different areas of the world as well as different floors and rooms inside a building we devised four navigation strategies which are controlled by a prop on a single drawing tablet. In collaboration with instructors at a special education school we constructed tasks which teach procedures from everyday life. These tasks focus on navigation through different rooms in combination with a two-dimensional card-sorting game which requires ordering different steps of a familiar task. The subsequent evaluation of our system indicated a wide acceptance by the users and showed promising learning results. Our system differs from existing approaches through the use of intuitive prop-based navigation in a realistic virtual world with a navigation strategy tailored to mentally handicapped people. Our user study indicates that ProbonoWorld is easy to understand and supports learning processes.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Three-Dimensional Graphics and Realism]: Virtual Reality K.4.2 [Social Issues]: Assistive technologies for persons with disabilities

1. Introduction

3D graphics tools are of great interest for the education of mentally challenged people, but there are still few programs catering to their special needs [VCHS06]. Schools often use standard children's software instead. Unfortunately most programs use 2D graphics only. Virtual environments offer few, unconnected scenarios and only mouse and keyboard interaction is supported [VCHS06]. Props on a board have been shown to be an expedient input device for the training and education of mentally challenged children in a virtual environment [SGHF05]. The original implementation is, however, limited to a supermarket scenario in a single room represented by a board and additional wooden guidance structures, which prevents a wider use of this innovative concept.

This paper presents four navigation strategies which have been developed based on the props on a board idea to allow the use of a single board as representation of an arbitrarily expandable virtual environment consisting of multiple



Figure 1: User navigating through the virtual environment by moving a puppet-shaped prop over the board. Actions are initiated by pressing a button in the hat of the prop.

rooms, floors and buildings. No further structures are necessary to mark boundaries inside the environment. We evaluated our navigation strategies with children at a special needs school and chose the best navigation strategy for implementation in a virtual city environment. In this city users can execute tasks in different parts of a building or even across buildings solely controlled by a puppet-shaped prop on a board. These tasks focus on different aspects of everyday life whose mastery prepares for a more autonomous life after school. Our evaluation of two planning tasks with mentally handicapped children confirmed that the system is easy to control and comprehend and that ProbonoWorld represents an efficient learning environment. It was much enjoyed by the users and appreciated by the teachers.

2. Related Work

2.1. Virtual Reality in Special Education

Under certain conditions, virtual reality can be a helpful tool in education [Cla83], [Bri91], [VHV05], [VCHS06]. With special education, maximum realism in the learning environment is a fundamental principle of effective learning, thus groups of pupils are often brought into a real environment such as a supermarket for education [SGHF05]. However, this arrangement provides logistical difficulties (transportation, staffing, funding) as well as other obstacles early in training like unknown dangers, failure or social stigmatisation. Here, a simulation can provide a safe environment with maximum realism [DP93]. Transferring the experiences in the realistic virtual environment to the real world is considered to be little difficult [CSNT96]. [SM91] state: "Virtual worlds aren't pictures, they're places. You don't observe them, you experience them." This makes virtual reality an ideal tool for special education.

2.2. Educational Concepts for Mental Handicaps

To ensure a high learning success through our application, extensive studies of the structure and organisation of education for mentally handicapped pupils were conducted prior to planning the system. The school for children with mental handicaps in Germany is structured into five grades, from primary grade at around age 6 to Werkstufe ("working grade") at around age 16-18 [EWM06]. The schools are organised as all-day schools. As target audience of our educational game we concentrate on the Werkstufe. As our interviews with instructors revealed, in the Werkstufe, children are practically educated. The instructors focus on the capability to cope with subsequent occupational challenges and to live independent from parents. It is most important for the pupils to reach a high grade of autonomy in all aspects of life. The main aims at school are therefore: right use of the senses, space awareness, language comprehension, understanding of quantities and values and simple symbol recognition.

Our system supports these aims in two ways: First, the tasks we devised for our demo system reflect what is taught at school in setting tasks which have to be mastered to cope with everyday life such as preparing a meal, doing the laundry or writing a letter. Second, the virtual environment consists of common buildings with rooms in which these tasks have to be performed, such as the home itself, a supermarket, a post office et cetera, which also offers the opportunity of devising tasks which stretch more than one place like buying food at the supermarket and then preparing a meal from it.

3. World Structure

The virtual environment is divided into layers forming a tree structure as seen in Figure 2. The first layer represents a city



Figure 2: Layer structure of the virtual environment.

with several buildings which can be entered. On the second layer lies a central space in every building like a hallway with doors leading to different rooms or an office with several counters. The third layer contains a further subdivision of space, e.g. rooms. The user can move freely among the different layers by using entrance- and exit doors according to the tree structure of the layers. In detail, this means that a user standing in the city can reach a supermarket or her home, but has to walk into her home's hallway before she can reach the living room. The conscious movement from one layer to the next is also supported by the design of the input device as described in section 4.1.

Every instance on the third layer can be filled with one or more tasks for the user to complete. This requires that the user is able to identify the corresponding room, e.g. the kitchen for preparing a meal, without much effort. The individual houses and rooms were therefore given easily recognisable designs and unique colour schemes, like the pink home which has a garden, the yellow post office with a big posthorn sign or the grey office building with a glass front. Inside the houses, the doors and doorframes all have the same colour corresponding to the building.

4. Navigation and Interaction

A central issue in designing a system for mentally handicapped persons is the choice of a suitable input device and navigation strategy. The user must be able to move around and orientate himself intuitively and without difficulty. As

input device we therefore chose an isotonic device with position control in the form of a human-shaped prop on a board. [SGHF05] have already shown that this kind of device is very well suited as input device for mentally challenged children navigating in a 3D world. Section 4.1 details our input device.

We then developed and implemented four different strategies for navigation which varied in the way the environment is structured and in the way the user movements are mapped onto movements in the virtual environment. The strategies differ particularly in the way the transgression from one layer of the virtual environment to the next is handled. This was done to identify the strategy best suited for the special needs of the mentally handicapped users. Sections 4.2.1 to 4.2.4 give an overview over each of the four navigation strategies.

4.1. Input Device and System Hardware

Our prototype system was derived from the one used by [SGHF05]. It consists of a personal computer system running Linux, a monitor and a Wacom Intuos2 A3 pen tablet with an active area of 300 x 450 mm. The corresponding drawing pen was built into a wooden prop depicting a person as shown on Figure 3. A button was integrated into the hat of the figure. Interaction is realised by moving the prop

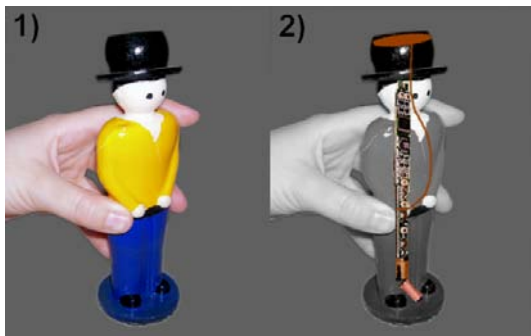


Figure 3: 1) The prop from the outside, 2) the pen with a button wired to the hat of the prop. The coil at the end of the pen is tilted to better measure prop orientation.

over the tablet as seen in Figure 4, with the whole of the tablet representing the current layer in the virtual environment. The movement of the prop is translated into the movement on the layer, e.g. the current room. The board is surrounded by a wooden frame with six indentations denoting entrances or exits, one at the top and bottom and two at the left and right side respectively. The software was written using the Avango framework [Tra99].

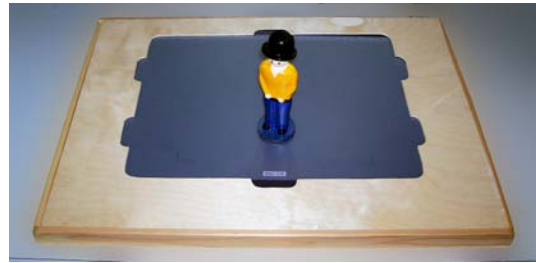


Figure 4: The prop on the board.

4.2. Navigation Strategies

The following sections describe the navigation strategies we devised for navigation with the prop on the board in a virtual environment.

4.2.1. Staircase Scenario

In this scenario (Figure 5), the movement between layers is emphasised by a staircase which has to be used to reach another layer, e.g. enter a building or move from the hallway into a room. To this end, a wooden boundary is positioned near the frame of the board, equipped with one exit door at the far end and five entrance doors at the front. The user

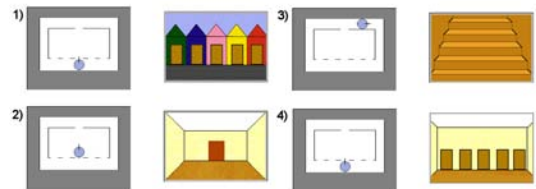


Figure 5: Navigation through the staircase scenario. 1) on the street, 2) in the hallway after entering a house, 3) on the staircase after leaving hallway through exit door, 4) second hallway with choice of room doors.

is first confronted with the five entrance doors corresponding to five houses (on the world layer) or five rooms (on the hallway layer or below). After passing through a door into a building she reaches the hallway layer. To leave the hallway again, she has to pass through the exit door on the far side. At this point, she can choose between a corridor to the left leading back outside, or a staircase going up on the right side which leads to the next level. Following the stairs she again is standing in front of five doors, this time symbolising room doors and visualised as such in the virtual environment. Passing through a door she reaches a room which can be exited once again through the door on the far side. This

time there is a staircase on the left going down and none on the right. Here the world can easily be expanded by adding a staircase upwards to yet another layer of the virtual environment, giving the opportunity for a building with a more intricate structure.

4.2.2. Street Scenario

This scenario (Figure 6) utilises two wooden boundaries at the near end of the board, both broken by five doors. This way, the board is divided into three sections corresponding to three layers in the virtual world. The tight layout of the

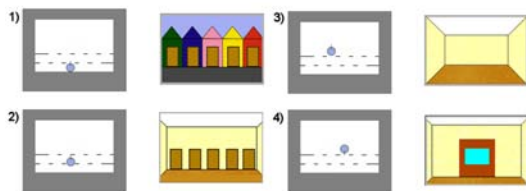


Figure 6: Navigation through the street scenario. 1) on the street, 2) in the hallway with choice of room doors, 3) in a room, 4) only one exit door is shown when turning around.

first two sections restricts the size of the matching layers to narrow corridors, the world layer is thus presented as a street with five houses next to each other. Moving through one of the doors the user reaches a hallway with five adjoining doors leading to five rooms.

4.2.3. Button Scenario

The main features of this scenario (Figure 7) are the use of a button, inserted into the hat on the prop’s head for switching layers and the absence of additional barriers for walls. The world is arranged around a central location with up to six doors leading to other layers. In our implementation, the door closest to the user always marks the exit, while the other five doors lead to deeper levels. The user starts at the bottom

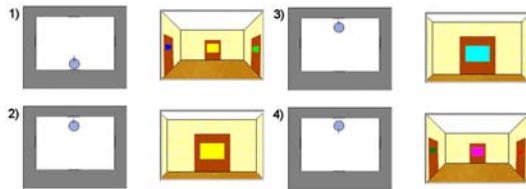


Figure 7: Navigation through the button scenario. 1) in the hallway with choice of room doors, 2) in front of one door, 3) on the other side of the door after pressing the button, 4) view of the next room after turning around.

end of the board. He is standing on a marketplace surrounded by five buildings. Moving toward a building, he reaches the entrance door when the prop has arrived at the edge of the board. To pass through a door into the next layer, the button on the prop is pressed. This initiates a change of the virtual environment, the world layer is hidden and the hallway layer becomes visible. The same procedure can be applied to any transgression from one layer to the next. To go back again, the user always has to cross the room and press the button while standing before the bottom door of the board.

4.2.4. Position Change Scenario

This scenario (Figure 8) was initially based on a Wacom drawing board which can also act as a display. The walls forming rooms could have been displayed on the board, with a vibration device simulating collisions with walls. The focus in this scenario lies on the deliberate change of the prop position by picking it up and setting it down when prompted by visual and acoustical clues. This omits the problem of the prop facing a wall and emphasises the passage from one layer to the next. The user starts at the bottom of the board,

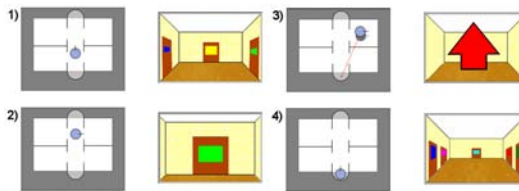


Figure 8: Navigation through the position change scenario. 1) in the hallway with choice of doors, 2) in front of one door, 3) request to relocate the prop after entering a room, 4) view of the next room after relocation of the prop.

where part of the wooden frame is carved out to make a niche for the prop. She faces a corridor (made of wood or displayed on the board) with five doors, one on the opposite side and the others along the walls. The door on the opposite end of the corridor leads to another part of the same corridor, thus leaving room for a scenario with several adjoining rooms. When crossing a door by either moving the prop into a room or reaching the far end of the corridor, clues are presented which prompt the user to move the prop back to its initial position. The board now represents the next layer (or another part of the same corridor).

5. Game Concepts

This section describes the game which was implemented after evaluating the navigation strategies and choosing the one best fitted. It consists of two different aspects: navigation in a realistic virtual environment with transfer between 2D and 3D world representations and the “planning task” which users can carry out.

5.1. Navigation

The prop was implemented as an isotonic device with position control, thus when the user moves it over the board, the same movement is conducted in the virtual world. When reaching the border of the board, the user has also reached the end of his current action space in the virtual environment (usually a room wall or a door). Doors are marked by indentations in the board frame (cf. 4.1) and movement between rooms takes place as presented in 4.2.3. The view of the world is as seen through the “eyes” of the prop representing the user. Navigation can therefore take place by both watching the virtual world on screen and blindly moving the prop or by viewing the prop and navigating it on the board toward a goal visible on board such as a door.

Associating a 2D representation with the real world and using it as a navigation aid is a situation commonly encountered, e.g. when reading a map to orientate oneself. This concept, successfully implemented in a more restraining way through wooden path boundaries by [SGHF05], is picked up here in a freer form which demands greater abstraction skills from the user. The only navigation aids are the door positions on the board frame and the orientation of the prop. An effort was made to create a realistic virtual world by using photo-realistic textures and detailed 3D models, as realism is a key to successful learning as stated in 2.1. Figure 9 shows views of the virtual environment.



Figure 9: Views of the world: the outside (left) and the hallway inside the home (right).

5.2. Planning Tasks

In daily life there are many procedures consisting of tasks which have to be carried out in a certain order. For example, to do the laundry one has to first sort the dirty clothes by colour and washing temperature, put them into the washing machine, select the desired program, start the machine and finally put the washing on a line. Mentally handicapped persons often have difficulties remembering the correct order of daily activities, thus sorting tasks into the correct sequence is a frequent exercise in special needs schools. Being able to handle such tasks independently is a crucial prerequisite for an autonomous life after school. We therefore chose those so called “planning tasks” as the main objective of our game.

When starting the game, the user is given one or more tasks to perform, e.g. “make a fruit salad”, all of which consist of a sequence of subtasks. The tasks are displayed on a bar on the left side of the view window, as seen in Figure 9. The bottom of the bar displays the name of the current location such as “Marketplace”, “Hallway” or “Bathroom”. The user, initially standing outside the buildings on the marketplace, has to first associate the given task with the correct building. There are five buildings in our implementation: home, post office, apothecary, supermarket and an office building. The “fruit salad” task is associated with the kitchen inside the home. The user thus has to navigate into the home and then into the kitchen. (Another implemented task, “write a letter”, is associated with the study inside the home.) When reaching the kitchen, the user sees a bowl of fruit standing on the counter. Approaching the bowl, a sign pops up which prompts the user to start the task. Signs carry symbols in addition to text, as a large percentage of users in our target audience are illiterate.



Figure 10: Two stages of task completion: during the game (left) and the finished state (right).

The planning task itself is implemented in a 2D view. The current prop position on the board is marked with a red dot cursor. Using the prop like a mouse, users have to drag and drop images of subtasks into the correct order as depicted in Figure 10. This is a one-to-one equivalent of exercises commonly done in special needs schools. After placing all pictures in a sequence at the bottom of the screen, the user is prompted to continue or make corrections. If the sequence is correct, a “well done” screen with a smiling face appears, if not, an unsmiling face is shown. The wrongly placed images are marked red and shift back into their starting positions, while the correctly placed ones are marked green and stay in place. Tasks can be adjusted to the user abilities by increasing or decreasing the number of subtasks, as it is done in special pedagogy.

6. User Studies

Two user studies were conducted for ProbonoWorld: One during the development process to find the best of the four developed navigation strategies and another after the implementation was complete to test the acceptance of the finished system and to evaluate the planning tasks. To analyse

the navigation strategies we implemented all four strategies in a prototypical system without sophisticated graphics and tested them with mentally handicapped children and adults (6.1). The result is described in section 6.1.5. In the second user study, done with the finished system, planning tasks (6.2) as well as handling and general acceptance (6.3) were evaluated. Evaluation was aided by program logfiles, videotaping of users during the test phases and handwritten notes recording specific occurrences.

6.1. Navigation Strategy Evaluation

A participatory development strategy was adopted in evaluating the navigation strategies before finalising our implementation: Tests were conducted with 16 students at a special education school and 14 adults at an accommodation for mentally challenged persons. For comparability, the participants were given the same task in every navigation environment with different users passing through different scenarios to avoid a familiarisation with the world which might distort results.

Starting on the highest layer, the "world", users had to find a room two layers below, the "kitchen". This required them to identify the home, enter the front door, identify the kitchen door from its doorsign, enter the kitchen and then find the way out again. The hallway doors were marked with symbols familiar to the user which showed stylised versions of the room behind the door.

Each user tested two navigation strategies. During the tests we collected feedback from the users, noted difficulties they might have in orienting themselves in the world, navigating through doors and making the connection between prop movement and movement in the virtual world. The following paragraphs list details of the evaluation of each navigation strategy, weighing positive and negative aspects of each.

6.1.1. Staircase Scenario Evaluation

The staircase scenario (4.2.1) required users to use a staircase to move between rooms and layers. Problems we encountered with this scenario were that there was no way of stressing that the staircase was going up or down apart from the visual clues. Another issue was that the wooden "doors" could not be actually closed on the board and thus remained open even though the virtual world showed a wall or locked door in their stead, this was especially apparent with users who navigated by the board and little by watching the virtual environment on screen. Also, the wooden boundary around the "staircase" disproportionately reduced the available space on the board left for the actual rooms. Caused by physical handicaps users spent more time passing the stairs instead of finding the right ways through the houses. The benefits of this scenario lie in the intuitive placement of the prop on the board, which is always as expected

by untrained users, a difficulty in all other scenarios as will be shown further on.

6.1.2. Street Scenario Evaluation

In the street scenario (4.2.2) all entrances were lined up along a street and a corridor respectively. One major drawback of this scenario is the limitation to three layers, which contradicts the idea of having an expandable virtual world unencumbered by hardware restrictions. Another disadvantage is the presence of five possible exit doors on the board while there is only one shown in the virtual world which led to some confusion, although this fact was ignored by most participants who simply moved the prop back outside without turning it toward the doors, thus moving backwards. Likewise most of the user found it difficult that the houses were not visible completely due to the limited view in the small "corridors". On the positive side, this scenario has a clear structure which is easily understood by most users who had no difficulty drawing the connection between sections on the board and layers in the virtual environment.

6.1.3. Button Scenario Evaluation

The button scenario (4.2.3) required users to press a button on the prop to pass through doors. Disadvantages of this setting are logical issues regarding the placement of the exit door, which we always placed at the near end of the board after tests showed this to be the most accepted solution, and the fact that, after each transgression, the prop has to be moved or turned to see the next room, as the prop's initial position after a layer change is facing a door or wall. The advantages of this setting are the unlimited extension capabilities as new layers can be added without problems. A passageway might also lead to another part of the same layer, this way it would be possible to realise a bigger world setting with one part of the houses surrounding one area and other houses built around an adjoining area which can be "seen" in the virtual world and reached the same way another layer would be reached, but without a visible door. Furthermore, the whole of the board can be used as room space. As this scenario is the one which best balances user friendliness and technical issues, we adapted it for the final version of the game.

6.1.4. Position Change Scenario Evaluation

The outstanding problem with the position change scenario (4.2.4) are the wooden walls which have to be used. This limits the room size on the lowest layer to less than a quarter of the board space, which is unacceptably small given the size of the prop. When using displayed walls, the walls can be switched off in the last room, but this leaves the issue of walls which the user can cross without much effort as a vibrating force feedback system is only a clue but does not bar the prop from crossing the wall. The benefits of the scenario are the very clear transits between layers, as the user has to make a deliberate effort to change layers, and the easy extendability.

6.1.5. Navigation Strategy Conclusion

In general, results varied significantly between participants due to their different handicaps. Our time measurements show that the second run was always faster than the first, which supports our observations that users rapidly comprehend and adapt to the operation of the system. Users finished their task fastest in the street scenario, which we ascribe to the fact that the board represented all layer depths of the world at once and movement between layers happened by simply pushing the prop through a wooden door on the board.

All criteria used to evaluate the strategies are summarised in Figure 11.

		Staircase	Street	Button	Position
Navigation Complexity	Orientation and Way finding	3	1	4	2
	Associability Board / World	4	1	2	3
	Navigation Difficulty	2	1	4	3
Ergonomics	3D World Layout	4	2	1	3
	Usage of Board Space	2	3	1	4
	3D World Extensibility	2	4	1	3
	Haptic Feedback	2	4	1	3
Overall Rank		4	2	1	3

Figure 11: Evaluation ranking, with marks ranging from 1 to 4, with 1 being the best rank.

Navigation complexity is described through the criteria of orientation and way finding, associability between board and world and navigation difficulty. Aspects like the three-dimensional world layout, the board space usage, extensibility and the haptic feedback make up the ergonomics category. For each criterion, the navigation strategies were ranked from one to four, with one being the best rating. Most importance was ascribed to extensibility, because with growing world size and therefore more options to act within the world, the possibilities for planning tasks spanning several places grow as well. We decide in favour of the button scenario as the one scenario which on average yielded the best results in terms of user friendliness and technical issues.

6.2. Planning Task Evaluation

The general usability of our input device, the interface design and the final navigation strategy were tested during a week-long test at a special education school. We especially investigated and evaluated the ability of users to use our system to accomplish planning tasks and their strategies to reach a solution.

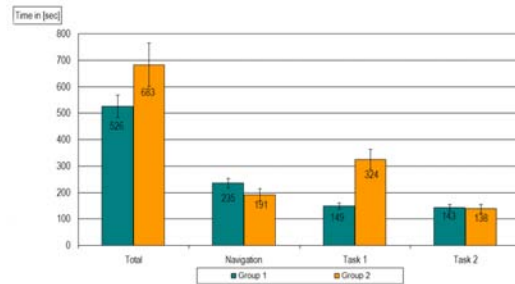


Figure 12: Time needed to complete different tasks.

24 students aged 8 to 16 participated in the following test scenario. All students of this rather inhomogeneous group were first briefly familiarised with the new system. The students were then parted into two groups corresponding to two planning tasks: "prepare a fruit salad" and "write a letter". Both tasks were provided at two difficulty levels of either three subtasks or five. One group had to solve the fruit salad problem in five steps and the letter problem in three steps, the other group vice versa. Note that the test group is quite inhomogeneous since the age ranges from 8 to 16 years.

To evaluate our planning tasks, we measured the time it took the students to complete a task and the number of attempts it took them before completion (Figures 12 and 13). An attempt was considered finished when the user pressed the button indicating that he was done sorting the segments of a task and thought them in the right order. Of group 1, who had to solve the fruit salad task in three steps, 75 % managed the task at the first attempt. The letter task in five steps was then completed by 84 % at the first attempt. Group 2 started with the fruit salad task in five steps, the error rate being marginally different: 66.7 % managed at the first try, two students took three attempts. All students performed the second task, "write a letter" in three steps, without any errors. We interpreted this as evidence for swift comprehension of our system. While performing the tests we observed that many students were unchallenged by the degree of difficulty of the given problem design: 81.25 % of all given tasks were completed at the first try. Sixteen of the twenty-four students were able to consecutively manage both of the tasks without errors. Six tasks were accurately completed at the second try. A mere 6.25 % of all tasks were completed only after the third try. The study revealed that the form of the planning tasks is well suited for the users, the familiarity with sorting pictures to depict events in a chronological order makes it easy for them to understand the kind of task and thus they can concentrate on learning about the events themselves rather than spending a long time learning about the system. While tackling the planning tasks, navigating in

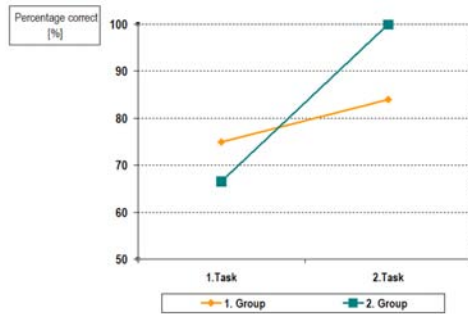


Figure 13: Percentage of planning tasks which were solved correctly within the first trial.

2D with the prop did not prove very difficult either, as the users were all familiar with mouse-like input devices.

6.3. Conclusion System Evaluation

All participants of our study accepted and embraced the system, even participants which had never used a computer were open-minded and highly motivated. Barriers using unknown technologies were cut quickly.

The interaction concept of using a prop on a board was adopted rapidly. The design of the prop amused our participants and reduced reservations. The orientation of the prop in relation to the virtual world, with the prop facing the same direction on board as the view frustum in the virtual one, was understood by everyone. The compact design of the figure allowed for easy handling, grasping and movement. The input device kept intact even when dropped to the ground, which is important given the inclination of some users to bash the prop against other objects.

All users were able to correctly associate a given task with a room inside the home and also correctly interpreted all informational signs at the room doors, thus went to the kitchen to make the fruit salad and to the study to write the letter. Navigating to the room itself presented no problem, either and the wooden indentations in the board frame additionally allowed for easy entrance finding. Some students were so intrigued that they even explored every possible room in the virtual world after completing their task. We thus presume that the choice of navigation strategy is accommodating the special needs of our target audience well.

There is already evidence that performance from a virtual learning environment can be translated into real-world behaviour [SGHF05], we therefore assume a similar improvement of real-life skills through ProbonoWorld.

7. Summary and Future Work

In this paper we presented a new media system that allows children with mental handicaps to train their skills for everyday tasks in navigation and orientation in combination with their cognitive planning abilities. Our intuitive interaction concept, which is especially important for mentally handicapped people, employed the props on a board form of interaction through a wooden puppet on a graphic tablet. We developed an appropriate navigation strategy for the props on a board approach, which also includes the possibility to extend the world nearly indefinitely. Subsequent evaluation showed great acceptance among students and teachers alike. Our system thus provides the possibility that children and adults with different kinds of disabilities are able to train their skills in various areas.

The participants of our study had hardly any problem solving the tasks. In order to increase the variability and to better measure effects of learning, further tasks of various difficulties should be developed and included in the study. This would also be better suited for students working at different skill levels.

Another area which might provide interesting possibilities for future work is the development of the two-dimensional card sorting tasks into exercises realisable in the three-dimensional real-world scenario. Performance of a task in a 3D environment further enhances realism (which, as stated earlier, is an important factor in virtual reality for special education) and could also train the correct usage of the necessary items, for example where to find the correct knobs on the washing machine and the stove. Nevertheless, whether even such a detailed virtual environment can serve to improve real-life performance remains subject to further investigation.

We can furthermore envisage several developments to help teachers support their pupils more efficiently. A feedback system which evaluates the achievements and the progress of an user would be a valuable tool and could be implemented by tracking and analysing variables related to navigation, orientation and problem solving. An authoring system would also allow teachers to develop new worlds and tasks and adapt the difficulty level to the abilities of each individual user.

8. Acknowledgements

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