A MULTI-DISCIPLINARY APPROACH TO THE CONTROL OF VIRTUAL ENVIRONMENTS FOR YOUNG PEOPLE WITH MODERATE TO SEVERE LEARNING DIFFICULTIES

TANJA LANNEN

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Anonymity

Please note that the author has modified a selection of figures within the thesis, in order to protect the anonymity of the subjects that took part in this research project.

Abstract

The purpose of this research was to examine the control of virtual environment (VE) navigation and interaction tasks for people with moderate to severe learning difficulties. This research stems from the development of VEs for people with learning difficulties and the identification that there are usability difficulties with the computer input devices, which are used to control the VE tasks. This investigation resulted in the following main extensions to the field of study:

- The application of a multi-disciplinary design methodology, resulting in the development of a design specification for the selection or design of usable VE input devices for young people with moderate to severe learning difficulties.
- The design and development of a new VE input system for young people with moderate to severe learning difficulties.

An evaluation was carried out to identify the specific usability difficulties that young people with moderate to severe learning difficulties experience, when using the joystick and mouse (commonly used devices) to control VE tasks. This evaluation concluded that it is important to consider user abilities, the VE tasks and the working environment, in order to select or develop usable VE input devices. This conclusion was supported by the following disciplines: human-computer interaction (HCI); user-centred design (UCD) and assistive technology (AT).

Consequently, a multi-disciplinary design methodology, which was based on the key activities of the user-centred design (UCD) process, was carried out. The first step of this methodology was 'understand and specify the context of use', which involved the analysis of the users, the tasks and the working environment, hence satisfying the conclusion of the background research. A new VE input system (VR1) was developed, based on the user, task and environment research. This prototype was then tested with a user group of young people with moderate to severe learning difficulties to evaluate its usability and to test the following hypothesis:

- The employment of the multi-disciplinary design methodology results in the design and development of a VE input system for young people with moderate to severe learning disabilities, which has greater usability than a commonly used system for this user population.

In order to test this hypothesis, a comparison was made between the usability of VR1 and the JM system (Joystick and Mouse: commonly used devices). The results showed VR1 to be significantly more usable than the JM system. Hence, the hypothesis was supported.

The results of this research have shown that the multi-disciplinary design methodology employed was a successful approach to this investigation. The application of this methodology has resulted in the production of a VE input system (VR1) that has the potential to provide improved VE control for young people with moderate to severe learning difficulties. Due to time limitations it was not possible to incorporate all of the identified design requirements into the VR1 prototype. Hence, to further increase usability, future prototype development should apply the complete list of device attributes from the design specification, along with the design refinement identified from the user-based assessment.

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1. Introduction

1.1 BACKGROUND

Virtual environments (VEs) are three-dimensional computer simulations, which respond in real time to the activity of their users. Significant research has been conducted in the application of VEs for people with moderate to severe learning difficulties. For example, the virtual city has been developed to teach independent living skills to this user population (Cobb et al, 1998). Research, which is rooted in developmental psychology theories, has indicated the following benefits in the use of VEs for people with learning difficulties:

- Encourage active involvement in learning and give the user control over the learning process (Pantelidis, 1993)
- Allow users to learn by making mistakes within a safe environment
- Avoid abstract thought, which has been found to be particularly challenging for people with learning difficulties (Donaldson, 1978)
- Allow users to can take part in activities or visit places that are inaccessible to them in real life
- Minimise the effects of many physical disabilities

However, further research in this area has highlighted usability difficulties with the computer-input devices, which are used to perform the VE tasks. For example, from an evaluation of the aforementioned virtual city, it was found that individuals differed in the amount of support required to use the input devices; joystick for navigation and mouse for interaction (cobb et al, 1998). It was also stated that navigation was found to be one of the most difficult tasks to do.

1.2 PURPOSE OF RESEARCH

The purpose of this research was to examine the control of virtual environment (VE) navigation and interaction tasks for people with moderate to severe learning difficulties. This research stems from the development of VEs for people with learning difficulties and the identification that there are usability difficulties with the computer input devices, which are used to control the VE tasks

1.3 FIRST STEPS

Input device evaluation

This evaluation was carried out to identify the specific usability difficulties that people with moderate to severe learning difficulties experience, when using the joystick and mouse (commonly used devices) to control VE tasks. The evaluation concluded that it is important to consider the physical and cognitive abilities of the user group, the tasks that the user must complete with the input devices, and the environment in which the tasks will be performed, in order to select or develop usable VE input devices.

Supporting literature

The main disciplines that related to the topic of research were examined: human-computer interaction (HCI); design for disability and assistive technology (AT). The design for disability research pointed to the discipline of user-centred design (UCD). The result of this research was that the disciplines of HCI, UCD and AT all supported the conclusion of the input device evaluation:

- In order to select or design a usable computer interface it is important to know the user, the task and the environment.

1.4 MULTI-DISCIPLINARY DESIGN METHODOLOGY

In order to address the conclusion of the input device evaluation, a multi-disciplinary design methodology, which was based on the key activities of the user-centred design (UCD) process, was carried out. According to the ISO 13407 European Standard (Human-centred design processes for interactive systems, 1999), these key activities are:

- Understand and specify the context of use
- Specify the user and organisational requirements
- Produce designs and prototypes
- Carry out a user-based assessment

2. Background

2.1 VIRTUAL ENVIRONMENTS

Virtual reality (VR) is concerned with using computers to create 3D scenes with which one can navigate and interact. Navigation and interaction require real time graphics, which implies fast computer processors. During the 1990s people accepted a wider definition of VR: PC (personal computer) systems emerged that were capable of displaying real-time images of 3D environments and the term virtual environment (VE) was introduced (Vince, 1998). A screen shot from the virtual city (Brown, 1999) is pictured in Figure 1.

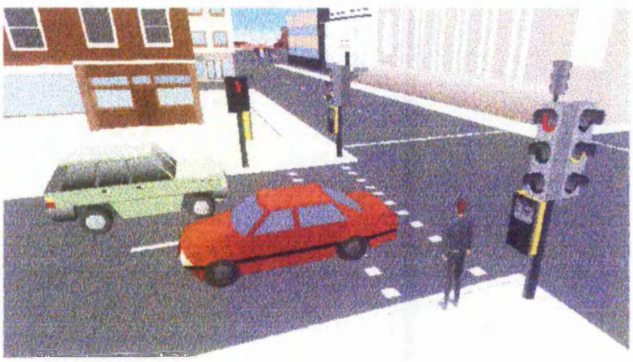


Figure 1. The virtual city

2.1.1 Navigation and interaction

Navigation

VE Navigation ranges from completely automatic to self-controlled. For automatic navigation user input is used to initiate events and navigation of the viewpoint occurs automatically, controlled by the computer. Self-controlled navigation is performed with a computer input device such as a joystick, mouse or keyboard. 2 degrees of freedom navigation (self-controlled) will allow movement forwards and backwards, turning left and right and side-step. Finally, navigation can be in the first person or third person view. In the first person view the user sees what he/she would see with his/her own eyes in the VE. With the third person view the user controls an avatar (Linden et al, 2000).

Interaction

VE interaction includes activating VE objects (i.e. opening a door), moving VE objects from one place to another or using one object with another (i.e. using a spoon to take some sugar from a sugar bowl) (Cobb, 2001).

2.1.2 Systems

VR systems can be divided into three groups: immersive, non-immersive and hybrid. Immersion increases the sense of presence in the virtual world. The following definitions are taken from a book entitled 'Virtual Reality Systems', by John Vince (Vince, 1995):

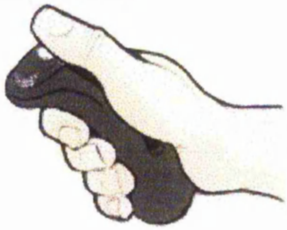
- *Immersive systems*: replace our view of the real world with computer-generated images that react to the position and orientation of the user's head.
- *Non-immersive systems*: leave the user visually aware of the real world but able to observe the virtual world through some display device such as a graphics workstation. A desktop VE system is classed as non-immersive.
- *Hybrid systems*: permit the user to view the real world with virtual images superimposed over this view – such systems are known as 'augmented reality' systems.

Input devices

Navigation: in immersive VR, navigation can be achieved by tracking the position of the user's head in three dimensions. Alternatively a 3D mouse (see Figure 2a) can be used. A 3D mouse is a hand-held device containing a tracker sensor and some buttons, and is used for navigating or picking objects within a VE. Navigation with a desktop VE system is controlled using a suitable computer input device, such as a joystick or 3D mouse.

Interaction: The data-glove (see Figure 2b) is a popular interaction device for immersive VR. When worn by the user, its position in space and finger positions are relayed to the host computer. A 2D mouse is commonly used for interaction with a desktop VE system.

a. 3D mouse



b. data glove

Figure 2. VR input devices

Output devices

Force feedback: force feedback devices are also known as haptic devices, as they provide some form of sensory feedback through the tactile senses. With these devices it is possible to touch, weigh and grasp virtual objects. A very effective haptic device is the PHANToM Haptic Interface System from Sensable, Inc. Force feedback joysticks are also available that can provide forces to oppose a user's commands.

Displays: the display device used is a major determinant of the level of user immersion in a VE. Immersive systems may use one of the following devices: HMD (Head Mounted Display) unit; panoramic screen; CAVE (Cave Automatic Virtual Environment) or retinal display. A HMD unit and CAVE are depicted in Figure 3a & b.

a. HMD unit

b. CAVE

Figure 3. VR displays

The panoramic screen is spherical and can be in the form of a dome, with a large horizontal and vertical field of view. These screens are used in military and commercial flight simulators. A CAVE is constructed from a number of back projection screens. Inside the CAVE, the user wears shutter glasses and tracking technology is used, so that wherever the user looks, a stereoscopic view is seen. With this set-up the degree of immersion is very high. The Human Interfaces Laboratory at the University of Washington is developing a retinal display that directs laser light direct onto the eye's retina (Vince, 1998). For a non-immersive desktop system the VE is displayed on a standard PC monitor (see Figure 4).

Figure 4. Desktop VE system

2.1.3 Applications

One of the first applications of VR technology was in flight simulation to train pilots within a safe environment. VR use is continually progressing in many areas, such as medicine, Computer Aided Design (CAD), entertainment, education and rehabilitation:

Medicine: one of the medical applications of VR is for keyhole surgery. VR simulators have been developed to assist with training for this delicate operation.

CAD: VR applications in this area include 'walk through' assessment of a building for architectural design and human factors modelling for ergonomic design. An example of VR in ergonomic design is Jack, a virtual 3D human model incorporating 68 joints. When Jack is placed in a VE, it is possible to explore human factors such as reach space, field of view, joint torque load and collision.

Education: VR in education would come under the broader heading of Computer Aided Learning (CAL). Examples of educational applications include: exploration of places, which would be fairly inaccessible, e.g. jungle and planets; study of abstract concepts, e.g. algebra and the study of things that are impossible to see with the naked eye, e.g. molecules (Cromby, 1996).

Rehabilitation: Davies et al have undertaken research into using VR as a complementary tool for medical practitioners in the assessment and rehabilitation of people who have suffered a Traumatic Brain Injury (TBI) (Davies et al, 1999). This study showed positive results, including the identification that VR technology could be beneficial as an early assessment tool for TBI patients who are also physically injured. In a related line of research to Davies et al, Rizzo et al report on the development and investigation of VR systems that target cognitive processes and functional skills that are of relevance to a wide range of patients populations with Central Nervous System (CNS) dysfunction (Rizzo et al, 2000). Parsons et al propose that VR could be beneficial for adults with Asperger's Syndrome (AS), who are characterised as having significantly impaired social understanding (Parsons et al, 2000). They state that, as VR offers a stable and predictable environment in which interaction can take place with less anxiety than a 'real world' situation, VEs could provide the ideal method for the development of social skills amongst adults with AS.

2.1.4 Research VE system and task

This research project is focused on VEs that would be used for education, training or entertainment purposes, which are presented on a non-immersive desktop VE system. The navigation tasks are self-controlled, allowing the following movements: forwards; backwards; turning left/right; side-step and look up/down. The interaction tasks only involve activating VE objects (not moving VE objects from one place to another or using one object with another).

2.2 LEARNING DIFFICULTIES

2.2.1 Definitions and requirements

The term learning difficulty has been defined as a delayed development in one or more of the processes of speech, language, reading, writing, arithmetic or other school subjects (Kirk and Bateman, 1962). A person with learning difficulties often has an associated communication, physical, sensory or behavioural difficulty. Development and quality of life, for people with a learning difficulty, can be enhanced through education, training, social support and health care (Welsh Health Planning Forum, 1992). The Disability Discrimination Act 1995 (DDA) states that a person has a disability if he or she has a physical or mental impairment that has a substantial and long-term adverse effect on his or her ability to carry out normal day-to-day activities.

The Intelligent Quotient (IQ) is used to classify four degrees of learning difficulty: mild (IQ between 55 and 69); moderate (40 to 54); severe (25 to 39) and profound (below 25). This research is concerned with the control of VEs for young people with moderate to severe learning difficulties. Gleitman et al have described the level of functioning at school age (6 – 20 years) and in adulthood (21 years and over) for each degree of learning difficulty (Gleitman et al, 1999). Table 1 details these functional descriptions. It is important to note that the definitions of learning difficulties will vary internationally.

Table 1. Level of functioning at each degree of learning difficulty

Functioning at school age (6 – 20 years)	Functioning in adulthood (21 years and over)
Mild learning difficulty	
Can learn academic skills up to approximately sixth-grade level by late teens; can be guided towards social conformity	Can usually achieve social and vocational skills adequate to maintain self-support; may need guidance and assistance when under unusual social or economic stress
Moderate learning difficulty	
Can profit from training in social and occupational skills; unlikely to progress beyond second grade level in academic subjects; may learn to travel alone in familiar places	May achieve self-maintenance in unskilled or semiskilled work under sheltered conditions; needs supervision and guidance when under mild social or economic stress
Severe learning difficulty	
Can talk or learn to communicate; can be trained in elemental health habits; profits from systematic habit training	May contribute partially to self-maintenance under complete supervision; can develop self-protection skills at a minimum useful level in controlled environments
Profound learning difficulty	
Some minor development present; may respond to minimal or limited training in self-help	Some motor and speech development; may achieve very limited self-care; needs nursing care

Cognition and learning

Persons with learning difficulties require specific programmes to aid progress in cognition and learning. These persons may require some or all of the following:

- flexible teaching arrangements
- help with processing language, memory and reasoning skills
- help and support in acquiring literacy skills
- help in organising and co-ordinating spoken and written English to aid cognition
- help with sequencing and organisational skills
- help with problem solving and developing concepts
- programmes to aid improvement of fine and motor competencies
- support in the use of technical terms and abstract ideas
- help in understanding ideas, concepts and experiences when information cannot be gained through first hand sensory or physical experiences

Sensory and/or physical needs

As stated previously, a person with learning difficulties often has an associated communication, physical or sensory difficulty. The sensory range extends from profound and permanent deafness or visual impairment through to lesser levels of difficulty. Problems in these areas may also be temporary. Physical impairments may arise from physical, neurological or metabolic causes that require no more than appropriate access to educational facilities and equipment; whilst other physical problems will produce more complex learning and social needs. The following requirements will help to overcome any physical or sensory difficulties:

- flexible teaching arrangements
- appropriate seating, acoustic conditioning and lighting
- adaptations to the physical environment
- access to alternative or augmented forms of communication
- provision of tactile and kinesthetic materials
- access to different amplification systems
- access to low vision aids
- access through specialist aids, equipment or furniture
- regular and frequent access to specialist support

2.2.2 Research user population

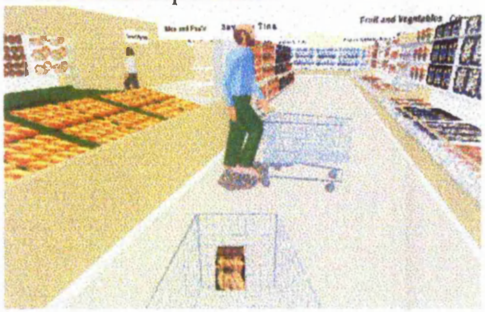
This research project is concerned with the control of VEs for young people with moderate to severe learning difficulties (people who are borderline moderate to severe or have severe learning difficulties. With reference to table 1, these users have the ability to talk or can learn to communicate, e.g. using Makaton (a language system for people with a wide range of generic learning difficulties). Additionally, these users often have an associated physical or sensory difficulty (see previous section: sensory and/or physical needs).

2.2.3 VEs for people with learning difficulties

Significant research has been conducted in the application of virtual learning environments (VLEs) for people with learning difficulties. VIRART (the Virtual Reality Applications Research Team) have developed the following VEs for people with learning difficulties: the Makaton programme; the virtual factory; the virtual tenancy and the virtual city. The Makaton VE programme was developed to assist pupils with learning difficulties in learning this language (Brown et al, 1997). The virtual city was developed to teach independent living skills to people with learning difficulties (Cobb et al, 1998). This virtual city included the following VLEs: house; supermarket; café and transport system. A screen shot from the virtual supermarket is pictured in Figure 5a.

More recently, Rose et al have investigated the use of VR in vocational training of people with learning difficulties (Rose et al, 2000). In this study, a questionnaire survey identified catering as the most popular choice for a virtual training package. A preliminary evaluation of a virtual kitchen showed some positive transfer of training to a 'real world' kitchen test and provided clear justification for further development of this type of training. A VLE has been developed to teach independent travel skills to people with learning difficulties (Lewis, 2000). More specifically, this VLE was designed to train these users how to reach the Millennium Dome in London, for the Mencap Enter2000 Virtual Reality Conference. Finally, the virtual courtroom (see Figure 5b) has been developed to enable people with learning difficulties to experience the activities of a courtroom setting and to practice the tasks that would be required of them, should they be asked to attend a hearing (Cook, *in press*).

a. The virtual supermarket



b. the virtual courtroom

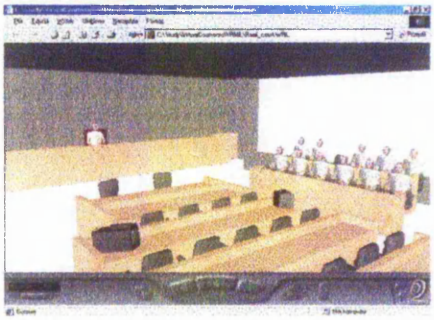


Figure 5. VEs for people with learning difficulties

Preference of desktop VR

Desktop VR systems are the preferred set-up for people with learning difficulties due to the unresolved health and safety issues associated with the use of HMDs. These health and safety issues include: nausea and dizziness (Regan & Price, 1994); deleterious effects on visual acuity (Mon-Williams et al, 1993) and isolation (Travis et al, 1994), as the social isolation of people with learning difficulties is often already great. In addition, desktop VEs facilitate peer and tutor interaction with the user, which is important for education (Vygotsky, 1978; Wood, 1988). Finally, VEs can be run on an entry-level PC. Hence, this set-up is realistically within the budget of most schools and other institutions.

2.2.4 Benefits of VEs for people with learning difficulties

An evaluation of the virtual city, by a group of users with learning difficulties, concluded that VLEs: provide interesting, motivating learning environments; are accessible to users with special needs; are representative of real world tasks and help users to learn some basic skills (Cobb et al, 1998). VEs are an effective, affordable, accessible and safe training and educational media for people with learning difficulties. Research, which is rooted in developmental psychology theories, has indicated numerous benefits in the use of VEs for people with learning difficulties (Standen, 1996):

Active learning: VEs encourage active involvement in learning and give the user control over the learning process (Pantelidis, 1993). Bruner (1968), Vygotsky (1978) and Piaget (see Wood 1988) state that self-directed activity is a central role in their developmental psychology theories. People with learning difficulties typically have little control of their everyday lives (Kuh et al, 1986, 1988) with many subject to the limitations imposed by physical or sensory impairments.

Facilitate playful activity: VEs allow users to learn by making mistakes within a safe environment. Play is integral in gaining knowledge about social rules (Garvey, 1974), the acquisition of specific metacognitive skills (Bruner, 1972) and the development of an adequate and accurate sense of self (Fein, 1991). In the real world, many people with learning difficulties are prevented from playful experiences, by discrimination, mobility or other impairments and the close observation of carers (Shakespeare, 1975).

Avoid abstract thought: where possible, VEs are realistic graphical representations of the real world. Hence, they avoid abstract thought, which has been found to be particularly challenging for people with learning difficulties, who are often described as 'concrete thinkers' (Donaldson, 1978).

Access new experiences: VEs can minimise the effects of many physical disabilities: people can adopt new perspectives, e.g. view the VE from a standing position, and people can take part in activities or visit places that are inaccessible to them in real life. The latter benefit is applicable to all users with learning difficulties.

2.3 CONTROL OF VEs FOR PEOPLE WITH LEARNING DIFFICULTIES

2.3.1 Usability difficulties

Research in VE applications for people with learning difficulties has highlighted usability difficulties with the computer-input devices, which are used to perform the VE tasks. For example, the aforementioned evaluation of the virtual city revealed that individuals differed in the amount of support required to use the input devices: joystick for navigation and mouse for interaction (Cobb et al, 1998). It was also stated that navigation was found to be one of the most difficult tasks to do. Neal et al also conducted an evaluation of VEs for users with learning difficulties (Neale et al, 1999). The same input devices, joystick and mouse, were used in this study and the following was found:

- Restricted movement space was difficult to navigate and led to user frustration
- Teacher assistance was required for some interaction tasks

It is important to note that participant selection for this study was based partly on ability to control the input devices. Although the navigation difficulty could be reduced with careful software design, this evaluation suggests that there is also room for improvement in the usability of the input devices.

It has been estimated that up to 40% of students in special needs schools may be excluded from using VEs merely because they find it difficult to manipulate the mouse and keyboard effectively (Brown and Stewart, 1996). Whilst using a virtual kitchen in a special school, teachers have suggested that improving the design of the control input (mouse) will make the system more usable for a wider range of students, particularly those with physical impairments (Cobb et al, 2001). A paper, which discusses the potentials of VEs for people with learning difficulties, states that there is a need to use or design input/output devices that do not add to the problems faced by users with physical and sensory impairments (Cromby et al, 1996). The following important statement is also made in this paper:

> 'Disabilities do not flow automatically from impairments, but arise at the organism/environment interface.'

Hence, it is necessary to select or design usable computer input devices to increase VE accessibility for people with learning difficulties. Linden et al have examined navigation and interaction in VEs for people with brain injury (Linden et al, 2000). They stated that one of the biggest hurdles is the devices that a person is required to use for imposing their will on the system. It was suggested that one reason for this human-VE interaction problem could be extraneous cognitive load (the load on the user above and beyond that of performing the task), which can be attributed to the usage of the tool itself. Too much extraneous cognitive load will distract the user from the task, as concentration will be focused on interacting with the VE. A further human-VE interaction problem is physical impairment. Virtual environments can exclude a number of potential users, including those who are physically unable to manage the input devices necessary to control a viewpoint and interact with objects (Boschian et al, 1999). This research, by Linden et al and Boschian et al, stresses the importance of matching the VE input device(s) to the cognitive and physical abilities of the users.

2.3.2 Most usable input devices

Cress and French (1994) report on a study that compared the performance of three subject groups on their use of the following computer input devices: touch-screen, mouse, keyboard, trackball and locking trackball (the trackball utilised could be programmed with non-locking or locking buttons). The three subject groups were as follows: 19 computer-experienced adults, 39 normally developing children and 15 children with learning difficulties. Three separate measurements of cognitive load (mastery, speed and user characteristics) were examined to compare input device difficulty. For the children with learning difficulties, it was found that gross motor abilities were significantly associated with their mastery of the touch-screen, trackball and locking trackball, which suggests that these devices present greater challenges to motor control abilities than the mouse and keyboard. However, for the same subject group, the mouse and keyboard (and locking trackball) were found to be significantly associated with pattern analysis abilities and would be expected to present greater cognitive load to children with poor development in this cognitive domain. Cress and French state that although the unsuccessful children might acquire device mastery skills with more extended training and/or development of further cognitive and motor abilities, at their present skill levels, the input devices represent a cognitive load that would interfere with task effectiveness.

For both the adults and children without learning difficulties, the touch-screen was found to be the fastest device. In a previous paper by Cress and Tew (1990) it was reported that computer input devices that involve more explicit sequencing of actions, such as cursor keys and locking trackball, require additional time. However, the touch-screen was found to be a much slower device for the children with learning difficulties. This was thought to be due to a control strategy that the majority of these subjects employed. They tended to produce a separate action for pickup and drag of the target object. This may have been done to reduce the cognitive complexity introduced by two simultaneous operations (pickup and drag) required to complete one task. Other evidence suggests that persons with learning difficulties do not learn tasks with simultaneous actions versus sequential actions equally well (Das et al, 1979). In relation to this evidence, Cress and French (1994) state that slower input devices that allow additional time for planning or correcting separate stages of operation may be easier to control successfully by less-skilled users. Finally, the adults were found to be considerably faster in using the computer input devices than the other subject groups. The reason that Cress and French (1994) suggest for this is the increase in perceptual/motor development and experience associated with age.

From this research by Cress and French (1994), there is no clear winner from the input devices tested (touch-screen, mouse, keyboard, trackball and locking trackball) that would provide adequate computer access for children with learning difficulties. The devices investigated were found to be either physically or cognitively challenging for this user population. These findings support the following point that was raised in the previous section describing usability difficulties: it is important to match the VE input device(s) to the cognitive and physical abilities of the users. The touch-screen findings for the subjects with learning difficulties suggest that these users find sequential actions versus simultaneous actions easier to learn and find input devices that allow time for planning or correcting separate stages of operation easier to control.

Hall (1993) conducted a study to investigate the effect of reducing the available degrees of freedom of a computer-input device on the control of VE navigation, for people with learning difficulties. Initially, a pilot experiment was conducted, which involved one student with learning difficulties using a spaceball for navigation and a mouse for interaction. The spaceball allows simultaneous movements in the X, Y and Z planes, aiming to give smooth control, which replicates real life motion. This pilot experiment revealed that the spaceball was not sufficiently robust for this user population and was replaced with a 6 degree of freedom joystick for further research. With 6 degrees of freedom, 3 joystick buttons are required to obtain all the movements, for example, to move left, the user is required to press the correct button and move the joystick left at the same time. The results showed that fewer navigation errors occurred as the number of degrees of freedom of the joystick was reduced from 6 to 2. The error reduction is probably due to the reduced complexity of the joystick, as no buttons are required for 2 degrees of freedom.

A study by Brown et al (1997) found that a joystick, limited to 2 degrees of freedom, is more suitable for navigation tasks than a keyboard or mouse. In this study, 6 students were observed using these devices to negotiate ski gates on a virtual ski slope. Although mistakes were observed, more gates were successfully passed using the joystick. The greatest degree of disorientation was displayed with the mouse. Additionally, the mouse was reported to affect some user's navigation to the point of frustration. Using a different VE, a touch-screen and mouse were assessed for interaction tasks and the students coped very well with both devices. However, difficulties were found in using the touch-screen to interact with small objects (partly due to parallax) and with the calibration of this device. The parallax occurred because the touch-sensitive surface was separated from the screen, and when taking into account the curvature of the screen the object may not have been exactly where it appeared to be. The author proposes that by replacing the touch-screen with a touch-monitor, the usability difficulties of parallax and calibration could be erased. However, some users may still find small VE objects difficult to interact with due to limitations in their fine-motor control ability.

From the research by Hall (1993) and the navigation research by Brown et al (1997) it can be concluded that, from the range of input devices tested, a joystick limited to 2 degrees of freedom is the most suitable navigation device. The research by Hall (1993) also highlighted the importance of matching the input device to the cognitive ability of the user, by showing that fewer navigation errors occurred as the number of degrees of freedom of the joystick was reduced from 6 to 2. For interaction, the research by Brown et al (1997) was less conclusive as it was reported that the subjects with learning difficulties coped very well with both the mouse and touch-screen. However, it was also noted that difficulties were found in using the touch-screen to interact with small objects (partly due to parallax) and with the calibration of this device. Hence, this research could point to the mouse as being the most suitable interaction device, although this would not correlate with the research of Cress and French (1994) that reported usability difficulties with both the mouse and the touch-screen.

2.3.3 Solutions

VE input devices for people with learning difficulties

Minimal research has been conducted in the area of VE control for people with learning difficulties. From the aforementioned study by Brown et al (1997) the following requirements for input device design or refinement were identified:

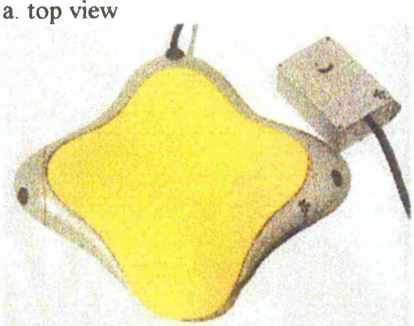
- Operable by people with fine-motor difficulties
- Modifiable
- Robust
- Easy to calibrate
- Affordable

Mojo: Lannen (1997) developed a prototype interface device, Mojo, which meets some of these requirements: operable by people with fine-motor difficulties, modifiable and affordable. Mojo, pictured in Figure 6, is an interactive seat that is designed to enable people with learning and physical difficulties to navigate within a VE, using gross-motor body movement. Mojo was compared with a joystick for control of a VE navigation task by students with moderate to severe learning difficulties, some of whom were also physically impaired (Lannen and Brown, 2000; Appendix A). The task was to navigate through four flagged gates in a skiing VE. Usability difficulties were experienced in using both devices:

- Joystick: unsteady control, missed gates and disorientation
- Mojo: rotation of device, rocking, missed gates, disorientation and button misuse

From the results it was clear that less disorientation occurred when using Mojo. However, both devices would require refinement to provide an adequate solution to VE navigation control for people with learning difficulties. Additionally, gross-motor movement is required to control Mojo, which will not provide the accuracy necessary for some navigation tasks.

a. top view



b. base view

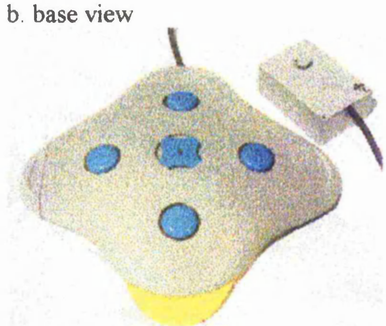


Figure 6. Mojo – interactive seat for VE navigation

The Tangible Interface: this device, developed by Starmer (2000), has also been designed for VE control for users with moderate to severe learning difficulties. This device is placed on top of a standard keyboard and comprises of physical objects, which represent those in the VE (see Figure 7). These include a coffee jar lid, kettle switch, spoon, kettle and carton of milk. Interaction with the physical objects causes activation of the virtual equivalent in a virtual kitchen.

Figure 7. The Tangible Interface.

This device has two advantages over mouse input. Firstly, there is direct correspondence between the objects used to activate control and the virtual object it represents. Secondly, the control input requires movements similar to real world actions. Observation and evaluation studies have shown that this provides greater access to the system and that users enjoyed this interface much more than the standard devices. The Tangible Interface holds promise for VE interaction for people with learning difficulties, but does not provide navigation control.

Assistive technology

Assistive technology (AT) has been defined as:

> 'any item, piece of equipment, or product system, whether acquired commercially off-the-shelf, modified, or customised, that is used to increase, maintain or improve the functional capabilities of individuals with disabilities.
> (USA , Individuals with Disabilities Act , 1990, pp. 101-476)

AT, sometimes referred to as adaptive or access technology, includes a wide range of high and low-end technology computer interface devices. Table 2 details a selection of the low-end technology. The devices listed in Table 2 have been designed to offer an alternative to the joystick and mouse, which are commonly used by people with learning difficulties for VE navigation and interaction. As previously stated, people with learning difficulties often have associated communication, physical or sensory impairments. Hence, for any of the devices, listed in Table 2, to be more usable than the joystick and mouse, they would need to be easier to understand, easier to manoeuvre and meet any sensory needs.

Table 2. A selection of low-end assistive computer technology

Alternative interaction devices
• Touch monitor • Trackball • Roller Plus joystick (Figure 8a): the advantages that this device has over a mouse are: joystick returns to central position when released, removable guard to avoid unwanted button presses and requires little space. Additional buttons allow only up/down or left/right movements of the pointer and control of pointer speed (Inclusive Technology). • Mouse Mover (Figure 8b): this device allows an individual to control all mouse functions using a combination of five single switches or a multiple switch. The Mouse Mover is suitable for people who cannot control the standard computer mouse, but can use single or multiple switches for access (QED).
Alternative navigation devices
• Jambox: this device plugs directly into the joystick (games) port of a PC and allows a user to control all game functions using a combination of four single switches (Keytools). • Wingman feedback mouse (Figure 8c): this device can be used as a mouse or a joystick. The hand interface is shaped like a mouse, but is attached to a base. The WingMan feedback mouse brings the benefits of sophisticated force feedback to force feedback games (Logitech).

a. Roller Plus joystick b. Mouse Mover c. Wingman Feedback mouse

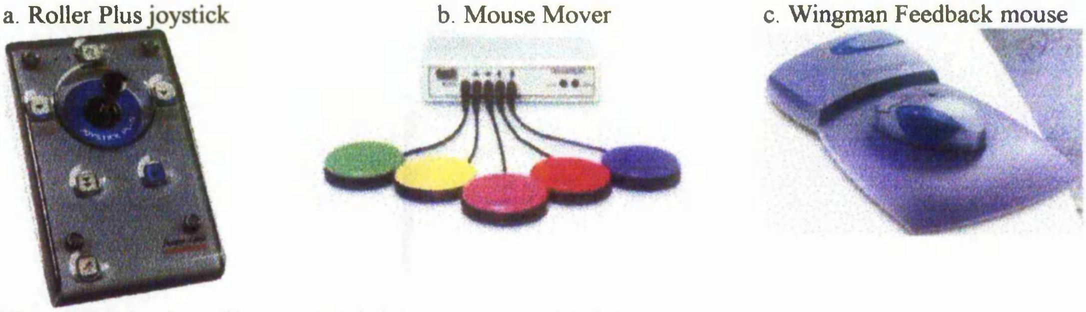


Figure 8. Selection of low-end assistive computer technology

For interaction, the touch monitor may be easier to understand than the mouse, for some users with learning difficulties, as interaction with this device is more direct. A button on the Roller Plus joystick restricts movement to horizontal and vertical. When this button is pressed, a user with learning difficulties may find the Roller Plus joystick easier to control than the mouse, due to the reduction in the degrees of freedom of movement. The Mouse Mover requires less physical control than the mouse and may also be easier to understand for some users with learning difficulties.

There are fewer alternative navigation devices available. The JamBox allows a combination of switches, suited to the user's physical ability, to be used to control navigation. Hence, it can be engineered to suit the physical ability of the user and could be easier to understand than the joystick. The WingMan feedback mouse can provide tactile feedback to the user, which could enhance understanding of VE navigation. Table 3 details a selection of the high-end technology.

Table 3. A selection of high-end assistive computer technology

• Tracker: head-tracking technology (Madenta) • Quick Glance: eye-tracking technology • Dragon Dictate software: voice recognition technology • The Gesture Control System: this system enables individuals wearing a DataGlove to perform complicated tasks through simple hand gestures. The DataGlove is a thin cloth with fibre optic cables running along its surface. When the fibres bend, the angular movement is recorded by sensors and these recordings are forwarded to the computer (Greenleaf Medical Systems). • Cyberlink interface system: the Cyberlink system combines eye-movement, facial muscle, and brain wave bio-potentials detected at the user's forehead to produce a full range of continuous and discrete computer inputs. A headband worn by the user detects the bio-potentials (Junker, 2000).

All of the high-end technology listed in Table 3, except the Gesture Control System, have been designed for hands-free operation. Hence, it would be particularly useful for people with physical impairment. However, this sophisticated technology is usually accompanied by an equally sophisticated price, which would be too great for many individuals with learning difficulties. In order to assess whether any of the high or low-end devices mentioned would be more usable than the joystick and mouse, they would need to be evaluated with an appropriate VE, by a group of users with learning difficulties.

2.4 SUMMARY AND CONCLUSION

Virtual environments (VEs) are 3D computer simulations, which respond in real time to the activity of their users and with which users can navigate and interact. VEs have been found to be of educational benefit for people with learning difficulties. Research in VE applications for people with learning difficulties has shown that there are usability difficulties with the joystick and mouse, which are commonly used by this user population for VE navigation and interaction. From research that investigated VE navigation for people with learning difficulties, it has been concluded that, from the range of devices tested, a joystick limited to 2 degrees of freedom is the most suitable navigation device. A similar conclusion has not been established for VE interaction.

Minimal research has been conducted to identify suitable VE input devices for people with learning difficulties. Two devices have been identified that were designed for VE control for people with learning difficulties. However, they do not sufficiently satisfy this human-VE interface problem. A wide range of assistive computer interface technology is available, which could provide a solution. However, identifying a usable solution from this range of technology would be quite time consuming.

As previously stated, research revealed that users with learning difficulties experienced usability difficulties with the joystick and mouse. However, this research did not provide detail of the specific problems observed. Hence, it was decided that a thorough evaluation of the joystick and mouse would be conducted to identify these difficulties and to clarify how research should progress.

3. Input Device Evaluation

3.1 INTRODUCTION

Research in VE applications for people with learning difficulties has shown that there are usability difficulties with the joystick and mouse, which are commonly used by this user population for VE navigation and interaction. However, this research did not provide details of the specific problems observed. The objectives of the input device evaluation were as follows:

- Identify the usability difficulties, which young people with moderate to severe learning difficulties experience when using the joystick and mouse for VE navigation and interaction tasks respectively
- Identify design requirements for future VE input device selection or development
- Determine how research should progress

3.2 METHOD

3.2.1 User group

14 pupils from the Shepherd School in Nottingham were selected to form the user group. The Shepherd School is a County co-educational day school for children aged 3-19 years with special education needs. This school serves a population of students with moderate to severe learning difficulties and is representative of schools of this nature in the United Kingdom. The school is divided into 4 departments: primary department (ages 3-11); secondary department (ages 12-15); 16+ department (ages 16+) and the planned dependent living department (classes providing specialised approaches for pupils with sensory and physical needs). Teachers from the primary, secondary and 16+ departments were asked to recommend pupils for the user group who: have the cognitive ability to understand the VEs; are not severely physically impaired (e.g. have some manual dexterity) and are interested in working with computers. The key characteristics of the user group are as follows:

- Gender: 7 male and 7 female
- Age range: 7 to 19 (5 primary, 4 secondary and 5 from 16+ department)
- Cognitive ability: 2 moderate/severe and 12 severe learning difficulties
- Physical ability: moderate physical difficulties including co-ordination, gross-motor and fine-motor difficulties. 1 pupil uses a wheelchair.
- Previous experience: 6 used VEs, 6 used joystick and 8 used mouse

3.2.2 Test administrator

The evaluation was conducted by the author. This entailed briefing the user about the evaluation, demonstrating the tasks and devices, prompting the user when necessary, de-briefing, video-recording and note taking. A carer was also present at some of the evaluation sessions. Figure 9 shows a demonstration of the joystick.

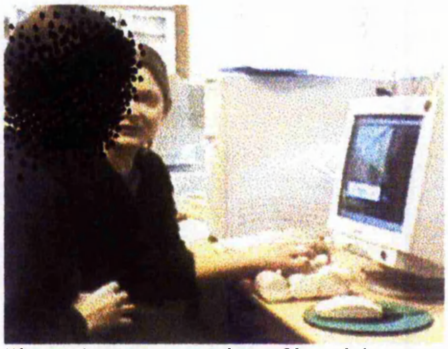


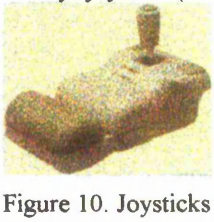
Figure 9. Demonstration of joystick to a pupil

3.2.3 Input devices evaluated

Joystick: two different joysticks were evaluated for navigation control. The first 10 pupils were observed using the Axys joystick, from Suncom Technologies (Figure 10a). The remaining 4 pupils used the Wingman joystick, from Logitech (Figure 10b). The reason for this change in joystick was that the stick on the Axys joystick was observed to be too short to grasp comfortably. The stick on the Wingman joystick is much taller and wider than the stick on the Axys joystick and is shaped to fit the hand.

Mouse: a standard 2-button mouse was evaluated for interaction.

a. Axys joystick (Suncom Technologies)



b. Wingman joystick (Logitech)

Figure 10. Joysticks used in the input device evaluation

3.2.4 Test facility

The evaluations took place at the Shepherd School in the 'Cyber Café' room. The lighting and temperature in the room was satisfactory. However, as this room was utilised for computer work by the older pupils, disturbances were expected. During the evaluation, other pupils did come and go from the room, but did not attempt to disturb the user.

3.2.5 Equipment

A PC was used to run the VEs, which were displayed on a colour monitor. Superscape Visualiser software was required to open the following VEs: virtual factory; café and supermarket. Sound was available and the workstation comprised of a comfortable chair and standard school desk. Video recording and note-taking equipment were used to record the sessions.

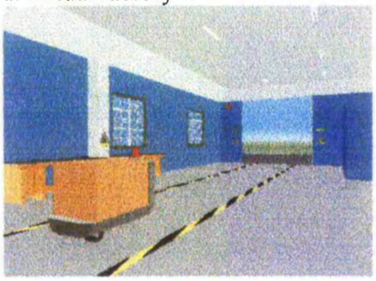
3.2.6 Tasks

Each pupil was asked to complete navigation and interaction tasks, using the joystick and mouse respectively, within the virtual factory, café or supermarket (developed by VIRART). A screen shot of each of these VEs is pictured in Figure 11. All of the pupils used the devices with the virtual factory. The café and supermarket were only used if a pupil became disinterested in the factory and further device assessment was required. The virtual factory tasks are listed in Table 4. The following movements were utilised for VE navigation: forwards, backwards and turning left/right. The interaction tasks only involved activating VE objects (not moving VE objects from one place to another or using one object with another).

Table 4. Virtual factory tasks

Task	Test
Enter building	Navigation (into building)
Put on protective clothes	Navigation (to cupboard); interaction (with cupboard and clothes)
Enter factory	Navigation (into factory)
Report oil	Navigation (to oil); interaction (with VE man and oil)
Report ladder	Navigation (to ladder); interaction (with VE man and ladder)
Report trolley load	Navigation (to trolley); interaction (with VE man and trolley load)
Go to wash basin	Navigation (to basin); interaction (open toilet door)
Wash hands	Interaction (with soap and tap)
Leave factory	Interaction (open toilet door); navigation (out of factory)
Take off protective clothes	Navigation (to cupboard); interaction (with cupboard and clothes)

a. virtual factory



b. virtual cafe

c. virtual supermarket

Figure 11. VEs used in the input device evaluation

3.2.7 Assessment measures

The following measures were used to identify the usability difficulties with joystick and mouse:

- Misuse of device: non-task related movement, harshness, pressing the wrong buttons, etc.
- Support required: spoken instruction, physical assistance, etc.
- Physical ability: sufficient strength, able to grip properly, etc.
- Workplace: able to reach, etc.
- Attention: on task, on device, on other
- User comments/reactions: positive, negative

Data recording: initially, notes were made on each user's performance with the VE tasks in a comments table. The data, which was relevant to the assessment measures, was then transferred from the comments table to the assessment measures table. Completed examples of the assessment measures table can be found in Appendix B.

3.3 RESULTS

The results of this evaluation were presented at ICDVRAT (the International Conference on Disability, VR and Associated Technology) 2000 (Lannen et al, 2000; Appendix A). The main usability difficulties identified from the evaluation sessions are listed in Table 5 and 6, along with suggested design requirements (*in italics*) to improve the usability of the devices evaluated.

Table 5. Usability difficulties/*suggested design refinements* (navigation and interaction)

Navigation	Interaction
Random movement of device –7, disorientation – 4 - *Clear, understandable operation* - *VE for training input device use* Too much left/right rotation, spinning – 5 - *Adjustable resistance to movement (may help to prevent some disorientation)* Trying to use for interaction – 3 - *Functional clarity for achieving navigation and interaction tasks* Button misuse – 6 - *Not easy to press buttons by mistake* Base held still by examiner – 4 - *Ensure that base of device remains stationary during operation* Physical help with some tasks – 6 Alignment guidance – 3 - *Able to use the device independently* - *Facilitates task completion* Used two hands – 2, tight grip – 2 - *Ergonomic design of device*	Random movement of device – 4 - *Clear, understandable operation* - *VE for training input device use* Frequent pressing of buttons – 3 Pressing wrong button – 3 - *Not easy to press buttons by mistake* - *Only possible to press buttons which are required* Physical help with some tasks – 4 Held still to press button – 1 - *Able to use the device independently* - *Consider physical abilities of the user group* Not gripping around the sides – 2 - *Ergonomic design of device*

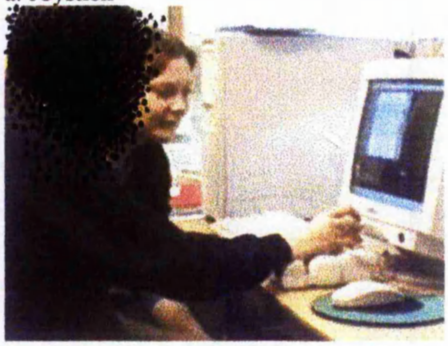
Note: the numbers represent the number of pupils

Table 6. Further usability difficulties/*suggested design refinements*

Prompting which device to use for a task – 3 - *Functional clarity for achieving navigation and interaction tasks* - *Only have one input device for navigation and interaction tasks* Encouragement, some distraction / distracted – 3 - *The device gives feedback* - *The device is motivating to use* - *Develop motivating VEs that are appropriate for age and developmental stage* Attention on devices when using them – 10 - *Device is 'transparent' (user can focus on task)* Weak grip – 1, shaky hand/arm – 2 - *Consider physical abilities of the user group* Desk too high – 3 - *Adjustable workstation* In Major Buggy (special chair) – 1 - *Consider accessibility to the workstation* Fidgets in seat – 2 - *Workstation helps to engage the user*

Note: the numbers represent the number of pupils

a. Joystick



b. mouse

Figure 12. Good control of joystick and mouse

3.4 DISCUSSION OF RESULTS

Physical ability and device construction

Figure 12a and b show good control of the joystick and mouse. Approximately half of the students in the user group were able to control the mouse and the joystick they evaluated quite well. However, this group still experienced usability problems with the devices, e.g. too much left/right rotation, button misuse, base held still by examiner and grip difficulties with the joysticks; base held still to press button and grip difficulties with the mouse (see Figure 13). These difficulties are largely due to the construction of the devices and the physical abilities of the user group, rather than to the user's understanding of how to use each device. It was observed that the Wingman joystick is easier to grip than the Axys joystick, due to its size and shape, highlighting the importance of ergonomic design for increasing usability (see Figure 14).

a. two handed grip

b. grip - fingers raised

c. base held still by test administrator

Figure 13. Grip difficulties and physical assistance

a. grip on Axys joystick

b. grip on Wingman joystick

Figure 14. Comparison of grips

Cognitive ability

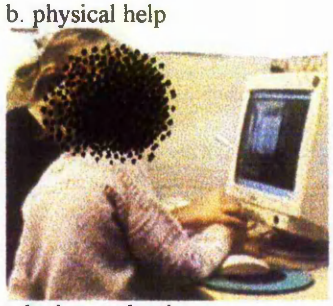
The difficulties experienced by other members of the user group are related to their cognitive understanding of how to use the devices, e.g. random movement and trying to use the joysticks for interaction and random movement and frequent pressing of buttons with the mouse. To overcome these difficulties it may be necessary to gain a deeper knowledge of the users' cognitive and perceptual abilities, so that the devices can be refined to an appropriate level of understanding. Figure 15a shows a user looking at the joystick she is controlling, instead of focusing on the VE task. The VE input devices need to be easy to use so that they become 'transparent', and allow the user to concentrate on the VE task.

Task and environment

As the joysticks and mouse were not specifically designed to be used by people with learning difficulties to control VEs, there may be certain VE tasks for which they are more difficult to use. This is evident from this evaluation, as physical help was required with all of the devices to complete some tasks by many of the students (see figure 15b). Finally, some members of the user group were distracted by other students and activities in the evaluation room (see figure 15c). Design guidelines were suggested, which should help to focus the pupils' attention on the VE, e.g. 'workstation helps to engage the user'.

a. attention on device

b. physical help



c. distraction

Figure 15. Further images from input device evaluation

3.5 SUMMARY AND CONCLUSION

The results of the evaluation indicated that a substantial number of people with moderate/severe learning difficulties have the cognitive ability to use the joystick (Wingman or Axys) and mouse to control VE tasks, but require refinement to both devices to improve physical usability. The results also showed that many people with moderate to severe learning difficulties experience extraneous cognitive load with the joystick and mouse. Hence, these people require a VE input system that is compatible with their level of understanding.

To conclude, this evaluation has highlighted the importance of considering the physical and cognitive abilities of the user group, the tasks that the user must complete with the input devices, and the environment in which the tasks will be performed, in order to develop a usable computer interface device. Hence, future research in VE control for users with moderate to severe learning difficulties should focus on identifying the requirements of the relevant users, tasks and working environment.

4. Multi-disciplinary design methodology

A thorough evaluation of the joystick and mouse, which are commonly used by people with learning difficulties for VE navigation and interaction, identified usability difficulties with both input devices and concluded the following:

- Future research in VE control for people with moderate to severe learning difficulties should focus on identifying the requirements of the users, VE tasks and the environment in which the VE system will be used.

4.1 HUMAN-COMPUTER INTERACTION

Human-computer interaction (HCI) is the study of the relationship between humans and the computer systems they use. It is concerned with the design, evaluation and implementation of interactive computing systems, and stresses that you should design for the user, the task and the environment. HCI is a multi-disciplinary subject concerned with all aspects that relate to interaction between users and computers, for example: computer science, psychology, ergonomics, design and engineering (Faulkner, 1998). Figure 16, adapted from the Essence of Human-Computer Interaction (Faulkner, 1998), shows the disciplines of HCI and their contributions.

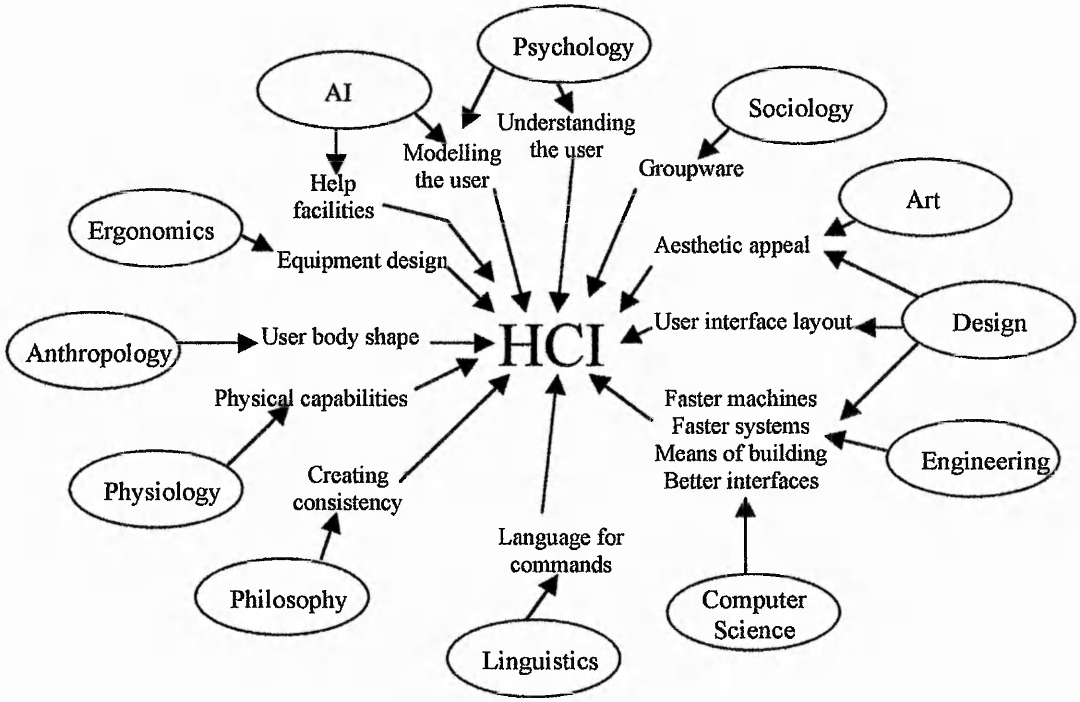


Figure 16. Disciplines of HCI and their contributions

4.1.1 Computer systems

There are four main parts to a computer system: computer processor, input, computer software interface and output (see Figure 17). As this study is concerned with researching VE input for people with learning difficulties, the focus will be on computer system input.

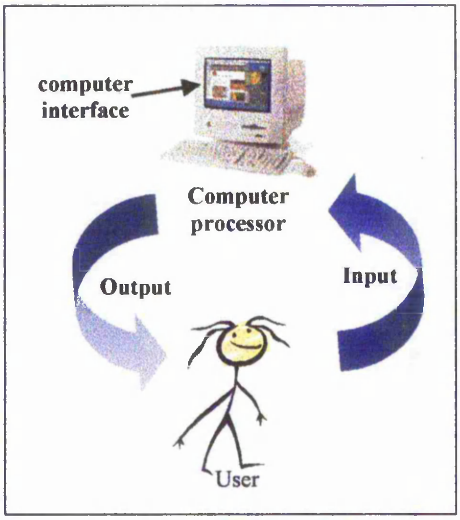


Figure 17. Computer systems parts

4.1.2 Information processing

Information is received and responses given via a number of input and output channels: visual, auditory and haptic. Information is then stored in memory: sensory, short-term and long-term memory. Finally, information is processed and applied (Dix et al, 1993). Table 7 details the elements of information processing, according to Dix et al.

Table 7. Elements of information processing

Input & output	Memory	Processing
Visual: seeing	Sensory	Reasoning
Auditory: hearing	Short-term	Problem-solving
Haptic: touch	Long-term	Skill acquisition

The visual, auditory and haptic channels are all important for human-computer systems. The visual channel is the primary source of information for the average person. However, if a computer user is visually impaired he/she will be more dependent on the other channels. The haptic channel is important in the development of input devices. For example, resistance to user movement is a requirement for joystick design (European Standard: ISO 9241-9: requirements for non-keyboard input devices), which helps the user to control his/her movements with the device.

4.1.3 The interface

Conceptual design

Computer users form a mental model of how an application works based on their prior knowledge and experience. This model will vary for different users and may change for individuals over a period of time. The computer interface must help the user to acquire an accurate mental model of the application and also accommodate for different user types. User and designers each have models of a system. Ideally the user's model should map onto the designer's model. One way of presenting a model of the system to the user is by using a metaphor. A good metaphor allows the user to form an accurate mental model of the system (Smith, 1999). For example, a magnifying glass (icon) could be a good metaphor for a text enlarger. Figure 18, adapted from Faulkner (1998), depicts the role of the interface.

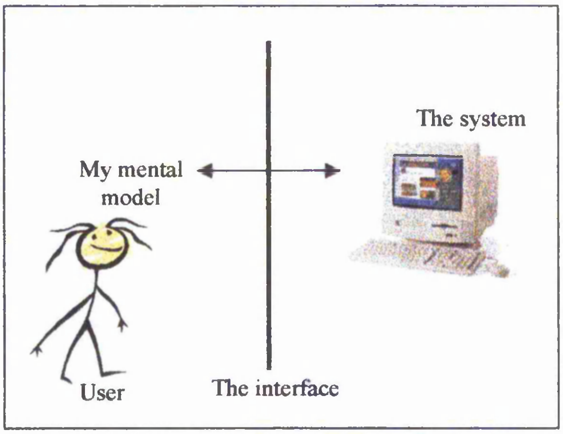


Figure 18. The role of the interface

Principles of interface design

A good computer system, like a good pair of shoes, should feel natural, comfortable and fit without the user being aware of it. The user should be able to concentrate on the task. It is stated by Schneiderman (1998) that ideally, a designer wants an easy to use, easy to learn, easy to remember interface that is appropriate to the task the user is trying to perform, is tolerant of human errors and which the users like to use. The principles of interface design, as stated by Faulkner (1998), are detailed in Table 8.

Table 8. Principles of interface design

Naturalness
• Reflect task syntax and semantics • Self explanatory • Avoid human pre-processing and post-processing • Adapt to the users needs
Consistency
• Input and output methods are consistent • User attention sought in the same way • Guessing not required
Relevance
• Only ask for relevant information • Require minimum user input/output for task completion
Supportiveness
• Adequate information provided for task completion • Adequate status feedback to help user continue the task • Know the level of understanding that the user has of the system or task
Flexibility
• Accommodate differences in user requirements, preferences and level of performance • Consistent for individuals, but recognise the need to tolerate a wide range of input syntax and semantics • Provide a variety of support levels and allow personalised output formats

4.1.4 Design for usability

Usability is a concept that has emerged from the ergonomics of HCI. In order to design an effective interface, HCI literature (Faulkner, 1998) states that the following questions should be answered:

- Who is the user?
- What is the task?
- What is the environment in which the system will operate?

Figure 19 depicts these questions, which form the HCI design framework. The questions are answered through an analysis of the user needs, the task and the working environment.

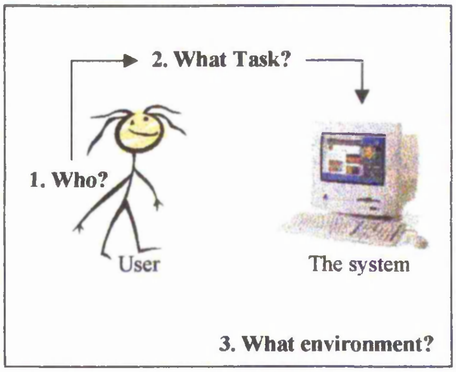


Figure 19. Key HCI questions

Usability engineering

Usability engineering strives to ensure that the finished product is what the user really wants and needs. The objective of usability engineering is to ensure that the system meets the requirements of the user, task and environment (Faulkner, 1998). Nielsen (1993) states that usability engineering involves setting up measurable usability goals and then designing and testing prototypes with the users in an iterative loop until the goals are met. The steps of the usability engineering process, as outlined by Faulkner (1998), are listed in Figure 20.

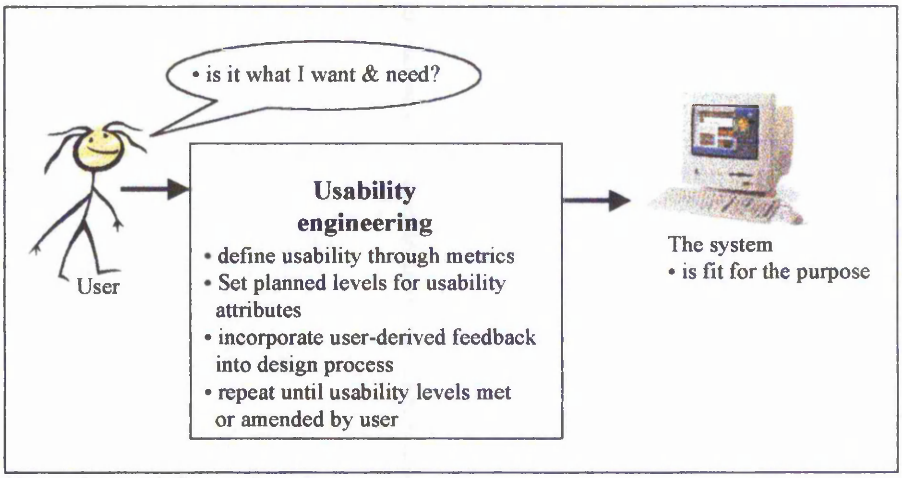


Figure 20. Usability engineering

Usability specification: this specification is a statement of the usability attributes that will be measured and is used as a basis for the usability evaluation.

4.2 USER-CENTRED DESIGN

A literature review in the area of design for disability was conducted. This resulted in a research focus on user-centred design (UCD). Many products are developed without considering the needs of elderly or disabled people. Often designers assume that they can rely on their own experience, rather than systematically assess the real experiences and requirements of the end users. UCD places an emphasis on understanding human attributes and needs, and involves developing products that satisfy user requirements (INCLUDE, 1998). Central to UCD is the concept of usability, which comes from the field of human factors. Human factors is a form of engineering that puts the human before the technology (for a broader definition see McCormick and Sanders [1985]).

The usability of a product is defined in ISO 9241, part 11 (European Standard that gives guidance on usability) as:

> 'The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use'.

As can be seen in this definition of usability, the usability indicators are:

- Effectiveness – accuracy and completeness with which users achieve specified goals
- Efficiency – resources expended in relation to the accuracy and completeness with which users achieve goals
- Satisfaction – freedom from discomfort, and positive attitudes of users towards the use of the product

For further discussion on usability see: Eason (1984); Nielsen (1993); Lindgaard (1994) and Lowgren (1993).

4.2.1 Principles of user-centred design

In line with the ISO 13407 European Standard (human centred design processes for interactive systems), the main principles of UCD are:

The active involvement of users and a clear understanding of user and task requirements: this is one of the key strengths of a UCD process. The involvement of the users in the development process provides valuable information about the context of use, the tasks and how the users are likely to work with the future product or system.

An appropriate allocation of function between users and technology: this involves the specification of which functions should be carried out by the users and which by the technology. The decisions should be based on the capabilities of the users versus the technology.

Iteration of design solutions: feedback from users becomes a critical source of information. Iteration, when combined with active user involvement, provides an effective means of minimising the risk that a system does not meet user and organisational requirements.

Multi-disciplinary design: UCD requires a variety of skills. Hence a multi-disciplinary team should be involved in a UCD process. The roles of this team can include the following: end-user; designer; human factors and ergonomics expert; HCI specialist and marketer.

4.2.2 Key user-centred design activities

According to the ISO 13407 European Standard, the key activities in a UCD process are:

- Understand and specify the context of use
- Specify the user and organisational requirements
- Produce designs and prototypes
- Carry out a user-based assessment

These activities are carried out in an iterative fashion, until the particular usability objectives have been attained. Figure 21, which is from the ISO 13407 European Standard, depicts the cycle of the user-centred design activities.

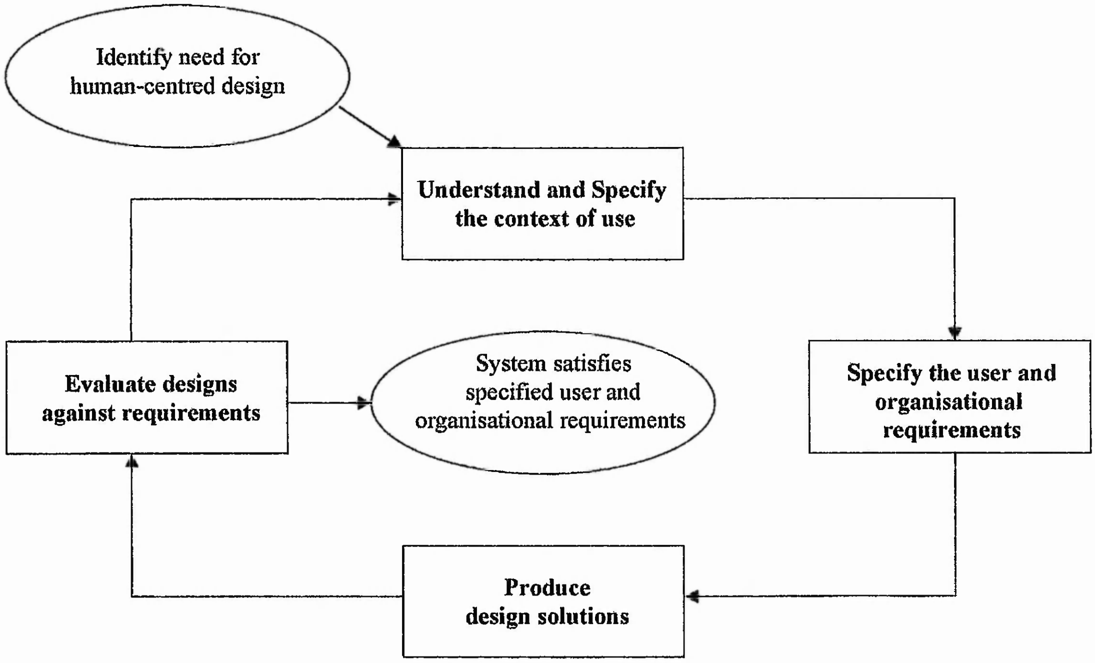


Figure 21. Key user-centred design activates

4.2.3 Design for all

The principle of a design for all strategy is that products should be usable by as wide a range of the population as possible. By ensuring that the least able can use a product, this maximises the number of potential users, and results in a product that is also easier for the more able user (INCLUDE, 1998). For example, if a telephone box was made more accessible to wheelchair users, by introducing automatic doors and greater internal space, it would also be more usable by a mother with a pushchair and shopping. Vanderheiden is a strong believer in design for all, stating that it is important to develop consumer products that are more accessible to disabled people (Vanderheiden, 1990).

Hence, the design for all strategy indicates that the design of a VE input device for users with learning difficulties will result in the development of an input device that is easier to use for people who are not cognitively impaired.

4.3 ASSISTIVE TECHNOLOGY SELECTION

4.3.1 Assistive technology assessment models

Several models of assistive technology (AT) assessment have been developed. A comparative analysis of 5 of these models has been conducted (Bromley, 2001). One of the models compared is entitled SETT, which is a 'guideline for gathering data in order to make effective AT

decisions'. The intended outcome of SETT is an appropriate match between the student, task, environment and technology used to accomplish the tasks within the environment. The comparative analysis concluded that all models in some capacity explore and assess the person, the tasks and the environment in which the tasks will be performed. Additionally, all models emphasise the importance of including a multi-disciplinary team in the assessment.

4.3.2 The ACE Centre

The ACE (Aiding Communications in Education) Centre offers a wide range of services to support communication and learning through the use of AT, including advice on the selection of suitable computer input devices. In order to select an appropriate computer input device, the ACE Centre state that it is important to assess an individual's easiest and most reliable method of computer access first and then look for the most appropriate system/equipment to match this ability (ACE Centre, 1999). The ACE Centre also stresses the importance of the involvement of a multi-disciplinary design team, due to the requirement that the assessors have a good understanding of the systems, equipment and the physical and cognitive abilities of the individual. This team could include a variety of professionals, e.g. a teacher, an occupational therapist and a speech therapist. The following points, stated by the ACE Centre (1999), should be considered in selecting an appropriate access control:

Physical abilities: identification of the strength, accuracy, speed and range of a controlled voluntary movement

- Mobility: the access method and equipment should not interfere with the individual's mobility
- Motor thinking: does the individual have the ability to predict the consequences of his/her motor activity?
- Cognitive ability
- Conceptual understanding: what is the individual's conceptual understanding of cause and effect, switch use and selection techniques (direct/indirect selection)
- Perceptual abilities

4.4 MULTI-DISCIPLINARY DESIGN METHODOLOGY

4.4.1 Combined research

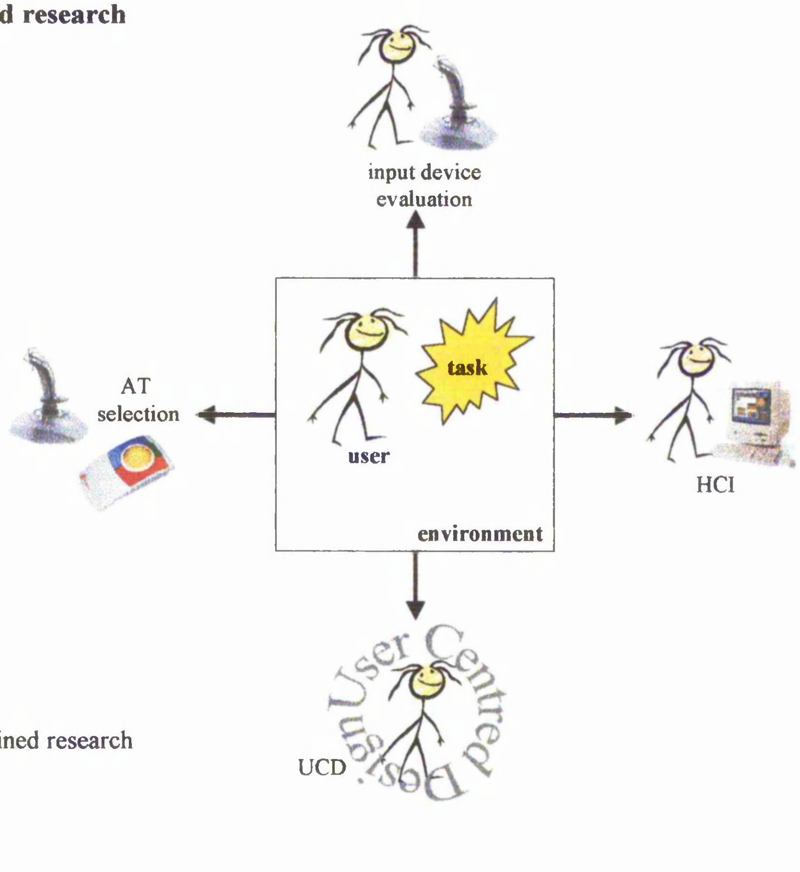


Figure 22. Combined research

The research conducted on HCI, UCD and AT selection, and the evaluation of the joystick and mouse, all point to the importance of considering the requirements of the users, tasks and environment for the selection or design of a usable product (see Figure 22). Hence, the decision was made to research these 3 important factors in order to be able to select or develop usable VE input devices for people with learning difficulties.

4.4.2 Multi-disciplinary design methodology

As stated in the user-centred design (UCD) section, the key activities in UCD are:

1. Understand and specify the context of use
2. Specify the user and organisational requirements
3. Produce designs and prototypes
4. Carry out a user-based assessment

These steps form the framework of the multi-disciplinary design methodology utilised for this research study. The methodology is described as mult-disciplinary as the following disciplines either provide the tools for a particular UCD step or will be consulted during the methodology:

- User-centred design: INUSE (Daly-Jones et al, 1999) and Userfit (Poulson et al, 1996) tools utilised
- Psychology: normative assessment tests utilised to identify user abilities in UCD step 1
- Ergonomics: design requirements research in UCD step 3
- Design: product design methods (Baxter, 1995) utilised in UCD step 3
- Engineering: for prototype design and development
- Human-computer interaction: usability engineering employed in UCD step 4

An outline of the resulting multi-disciplinary design methodology is as follows:

1. Understand and specify the context of use
   - User, task and environment analysis (tool: Usability Context Analysis (UCA); USERfit: Activity Analysis and Product Environment)
2. Specify the user and organisational requirements
   - Identify the design requirements (from UCA data, European Standards and relevant research)
   - Identify device attributes (tool: product analysis)
   - Design specification

3. Technology review
- Review computer interface technology (with reference to design specification)
4. Produce concept designs and prototypes
- Concept generation and selection (tools: product design methods)
- Embodiment design (tools: product design methods)
- Prototype manufacture
5. Carry out a user-based assessment
- Evaluation plan (evaluation method and usability metrics)
- Conduct usability evaluation
- Incorporate user-derived feedback into design process

Following the completion of the first 2 steps of the methodology, a technology review is conducted. The aim of this review is to identify any existing computer input devices that meet the requirements in the design specification or could be adapted to meet the requirements. If suitable input devices are identified, the 4th step of the methodology (produce concept designs and prototypes) would not be necessary and the 5th step (carry out a user-based assessment) would be carried out. If the technology review reveals no matched computer input devices or if adaptation is required, concept and prototype design would commence. The methodology is an iterative design process, as the steps are repeated until the usability metrics, defined in the evaluation plan, are met. A diagram of the multi-disciplinary design methodology is shown in Figure 23.

User group and usability team

User group: the active involvement of the end users is vital to the success of this methodology. For this study, the user group comprised of a representative group of students with moderate to severe learning difficulties from the Shepherd School.

Usability team: the involvement of a multi-disciplinary design team is reported in user-centred design and assistive technology literature and has been described by Brown et al (1999) in their use of a steering group to oversee the development of the virtual city project. For this study, a usability team was formed to advise and monitor the research at each stage of the methodology. This team included: an industrial designer; a psychologist; an occupational therapist; a physiotherapist; HCI experts; a human factors expert and learning difficulties experts.

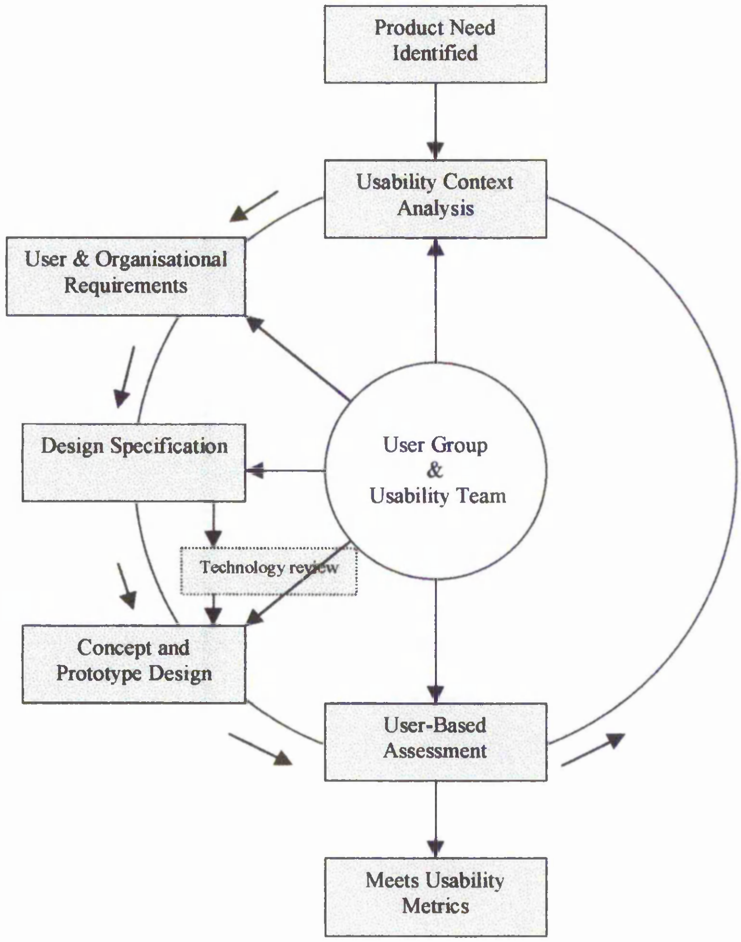


Figure 23. The multi-disciplinary design methodology

5. Understand and Specify the Context of Use

5.1 INTRODUCTION

This is the first step of the multi-disciplinary design methodology. The purpose of this step is to define the context of use of the VE input device(s), which involves the identification of the characteristics of the intended users, the tasks the users are to perform and the environment in which the users are to use the system (ISO 13407:1999). The Usability Context Analysis (UCA), available from NPL Usability Sěrvices (Thomas and Bevan, 1996), is a structured method for collecting the contextual information. In this method, the context questionnaire is followed to gather the data. The 5 major sections of this questionnaire deal in turn with the characteristics of the user, task, and organisational, technical and physical environment. The context questionnaire has been utilised in this study in order to collect the relevant contextual information, which is recorded in the context report (see Appendix F).

A selection of tools from the USERfit methodology (Poulson et al, 1996) have been used for the context and requirement stages (steps 1 and 2) of the multi-disciplinary design methodology. The USERfit methodology comprises a set of 9 summary tools designed to assist AT developers in addressing the issue of usability in design. The Activity Analysis (AA) and Product Environment (PE) tools have been utilised to compliment the context questionnaire from the UCA. Details of this step of the employed methodology are to be published (Lannen, *in press*; Appendix A).

5.2 USER GROUP

In order to research the user section of the context questionnaire, a user group was required. 21 pupils with learning difficulties, from the Shepherd School in Nottingham, were selected to form the VRD (Virtual Reality Device) user group. 14 pupils from this group took part in the Input Device Evaluation (Chapter 3). As with this previous evaluation, the selection of further pupils was achieved by asking the teachers to recommend pupils whom: have the cognitive ability to understand the VEs; are not severely physically impaired (e.g. have some manual dexterity) and are interested in working with computers. An additional aim was to select an equal number of male and female users across the primary, secondary and 16+ departments. However, this proved difficult to achieve, due to there being a greater number of males that met the selection criteria. Additionally, there were fewer pupils from the primary department that met the selection criteria. Table 9 details the gender and age of the user group.

Table 9. User group gender and age

User	Gender	Age	User	Gender	Age
Primary department			16+ department		
A	F	8:04	N	F	17:04
B	F	10:07	O	F	18:10
C	F	11:07	P	F	18:11
D	M	7:03	Q	M	16:11
E	M	8:04	R	M	17:08
F	M	9:03	S	M	18:00
Secondary department			T	M	18:09
G	F	12:10	U	M	19:03
H	F	14:10	V	M	19:04
I	F	15:07			
J	M	15:00			
K	M	15:02			
L	M	15:03			
M	M	16:04			

5.2.1 VRD (virtual reality device) user group party

A party was held to inform the user group about their involvement in the VE input device research. A short presentation was given using overhead projector slides (see Appendix C). The pupils were informed that their participation was greatly valued and would include: testing the joystick and mouse (already completed by the date of this party); looking at pictures, picking shapes and performing some exercises (user analysis); helping to choose a design and testing the new device. A teacher assisted during this presentation by using Makaton signing to ensure that the pupils understood. Following the presentation, the party commenced, with food, drink and music (all with a futuristic theme).

5.3 USER ANALYSIS

The first step of the User Analysis (UA) tool from the USERfit methodology requires the identification of the relevant stakeholders. The stakeholders are any groups of people who will come into contact or be influenced by the product under development. The UA tool then requires that the attributes of the stakeholders are researched and design requirements specified based on these attributes. For this research project the stakeholder groups would include: the end-users; educators; parents or carers; therapists and technical maintenance staff. However, this research study is focused on the end-users, who are the primary stakeholders. A future research study could include the identification of the design requirements for the other stakeholder groups.

As previously stated, the UCA context questionnaire was used to guide the collection of the contextual data. This included an analysis of the following user group characteristics: skills and knowledge; cognitive abilities and physical attributes. The user data was obtained through various sources, including normative assessment tests, the pupils' educational files (permission obtained), observation, video analysis and literature research. The resulting data was reported in the following sections: skills and knowledge; cognitive ability; physical ability; perceptual ability; communication; behaviour and motivation. This data is listed for the user group as a whole in the user analysis section of the context report, which can be found in Appendix F. The specific characteristics of 3 pupils (D, E and H) are also detailed in Appendix F.

5.3.1 Skills and knowledge

The skills and knowledge section of the context questionnaire includes the following questions:

- Experience in the methods that the product supports (virtual environments)
- Experience in using product with similar main functions to the new product (computer input devices)
- Background knowledge (computer experience)
- Qualifications (user attainments)

The relevant data gathered is shown in brackets. VE and input device experience had already been identified on the 14 pupils who took part in the Input Device Evaluation. This data was combined with that identified from the pupils' educational files (from annual review reports), which also gave details of user attainments. Table 10 shows a selection of the skills and knowledge data obtained (note: the numbers in Table 10 represent the number of pupils).

Table 10. Selection of skills and knowledge data

VE experience
• Used VEs before: 6
Input device experience
• Can use touch-screen: 19 (2 with motor difficulty) • Good joystick control: 9 • Joystick difficulty: 9 cognitive and 3 motor difficulty • Good mouse control: 10 • Mouse difficulty: 8 cognitive and 3 motor difficulty
Computer experience
• Enjoy using the computer: most pupils • Can switch on computer and load a program: 4

5.3.2 Cognitive ability

The cognitive abilities of the pupils in the user group were assessed using the British Picture Vocabulary Scale two (BPVS-II) and the Matrix Analogies Test Short Form (MAT-SF).

BPVS-II

This assessment test is designed primarily to measure a subject's receptive (hearing) vocabulary for Standard English. Additionally, the BPVS-II may be viewed as one element in a comprehensive test battery of cognitive processes. Vocabulary sub-tests have been proved to be among the most important contributors to comprehensive tests of verbal intelligence (Elliot, 1983 and 1990). Table 11 lists a selection of the BPVS-II results. The complete results are detailed in Appendix D.

Table 11. Selection of BPVS-II results

User	Gender	Age	Raw score	AE – CB	Score range
Primary department					
A	F	8:04	45	3:10 – 5:01	ELS – MLS
B	F	10:07	31	2:08 – 3:06	ELS
C	F	11:07	40	3:03 – 4:05	ELS
D	M	7:03	30	2:08 – 3:06	ELS
E	M	8:04	31	2:08 – 3:06	ELS
F	M	9:03	16	2:00 – 2:09	ELS
Secondary department					
G	F	12:10	58	5:02 – 5:05	ELS
H	F	14:10	35	2:10 – 3:10	ELS
I	F	15:07	79	7:02 – 8:04	ELS
J	M	15:00	55	4:10 – 6:01	ELS
K	M	15:02	58	5:02 – 6:05	ELS
L	M	15:03	48	4:02 – 5:04	ELS
M	M	16:04	62	5:07 – 6:10	ELS
16+ department					
N	F	17:04	68	6:01 – 7:04	ELS
O	F	18:10	30	2:08 – 3:06	ELS
P	F	18:11	48	4:02 – 5:04	ELS
Q	M	16:11	96	8:10 – 10:09	ELS – MLS
R	M	17:08	40	3:03 – 4:05	ELS
S	M	18:00	74	6:08 – 7:11	ELS
T	M	18:09	65	5:10 – 7:01	ELS
U	M	19:03	34	2:10 – 3:08	ELS
V	M	19:04	13	2:00 – 2:08	ELS

Explanation of results: the raw score (RS) is the score that the individual achieved on the test. The age equivalent (AE) indicates the age at which a given raw score is an average accomplishment for the group on whom the test was standardised. To allow for the inevitable element of error in any testing situation, a confidence band (CB) is calculated. The BPVS-II has a CB of 68%, which means you can be 68% certain that a person's true score lies within the limits indicated. Finally, a descriptive category of the subjects score is given: extremely low score (ELS); moderately low score (MLS); low average score (LAS); high average score (HAS); moderately high score (MHS) and extremely high score (EHS).

MAT-SF

The Matrix Analogies Test is utilised to assess non-verbal reasoning. The score that an individual obtains on this test gives a measure of non-linguistic cognitive functioning and can be considered in relation to the measurement of other skills, i.e. verbal ability. The MAT-SF is particularly useful for children with minimal language skills, as its content is language free (Naglieri, J.A., 1985). Table 12 lists a selection of the MAT-SF results. The complete results of this test are detailed in Appendix D.

Table 12. Selection of MAT-SF results

User	Gender	Age	Raw score	AE – CB	Stanine – CB
Primary department					
A	F	8:06	9	5:11 – 702	3 – 3
B	F	10:09	5	<5:00 – 5:11	1 – 1
C	F	11:09	6	<5:00 – 6:04	1 – 1
D	M	7:05	10	6:04 – 7:04	4 – 6
E	M	8:06	5	<5:00 – 5:11	1 – 3
Secondary department					
G	F	13:01	11	6:08 – 7:06	1 – 1
H	F	15:01	1	<5:00 – <5:00	/ – 1
I	F	15:09	8	5:06 – 6:11	1 – 1
J	M	15:02	13	7:02 – 8:03	1 – 1
K	M	15:05	8	5:06 – 6:11	1 – 1
L	M	15:05	10	6:04 – 7:04	1 – 1
M	M	16:06	10	6:04 – 7:04	1 – 1
W	M	16:01	9	5:11 – 7:02	1 – 1
16+ department					
N	F	17:06	9	5:11 – 7:02	1 – 1
O	F	19:00	7	5:00 – 6:08	1 – 1
P	F	19:01	8	5:06 – 6:11	1 – 1
Q	M	17:01	11	6:08 – 7:06	1 – 1
R	M	17:10	1	<5:00 – <5:00	/ – 1
S	M	18:02	8	5:06 – 6:11	1 – 1
T	M	18:11	7	5:00 – 6:08	1 – 1
U	M	19:06	3	<5:00 – 5:00	1 – 1

Explanation of results: the raw score (RS) and age equivalent (AE) have been explained in the BPVS-II results. As with the BPVS-II, a 68% confidence band (CB) has been used. Hence, there is 68% certainty that the individual's true score lies within the limits indicated. Stanines (S) divide the normal distribution into 9 units. Table 13 shows the recommended interpretation of the Stanine (S) scores for the MAT-SF.

Table 13. Stanine descriptions

Stanine	Stanine Description
1	At high risk of academic failure
2	At risk of academic failure
3	Academic problems are possible
4	Low average
5	Average
6	High average
7	Academic success is likely
8	Superior
9	Very superior

Discussion of results

Two of the pupils (F and V) achieved a much lower raw score on the BPVS-II than the rest of the user group (indicated by the shaded rows in Table 11). These pupils were removed from the user group before the MAT-SF assessments commenced. Of the remaining pupils, 18 scored in the extremely low score range (ELS) on the BPVS-II, and 2 pupils (A and Q) scored slightly higher, bordering the extremely low to moderately low score range (ELS – MLS).

Before beginning the MAT-SF tests, a pupil (W) from the senior department was selected to join the user group, bringing the total number of pupils in the user group to 21. Using the recommended stanine interpretations, a summary of the MAT-SF results are as follows:

- The scores of 18 pupils indicate *a high risk of academic failure*
- Pupil E's score lies between *high risk of academic failure* and *academic problems are possible*
- Pupil A's score indicates that *academic problems are possible*
- Pupil D's score lies between *low average* and *high average*

Hence, the combined results of both tests indicate that the majority of the pupils in the user group have severe cognitive difficulties, and that only a few of the pupils are bordering the moderate to severe level of cognitive functioning.

5.3.3 Physical attributes

The physical attributes of the user group were assessed using the Quick Neurological Screening Test Two (QNST-II), a Range of Movement test (ROM test) and the pupils' educational files.

The QNST-II

The QNST-II is an individually administered screening instrument, designed to assess areas of neurological integration as they relate to learning (*QNST-II, reference*). The tasks on the QNST-II (see Appendix D) provide an opportunity to observe the following in an organised manner:

- Maturity and motor development
- Skill in controlling gross and fine muscle movements
- Motor planning and sequencing
- Sense of rate and rhythm
- Spatial organisation
- Visual and auditory perceptual skills
- Balance and vestibular function
- Disorders of attention

QNST-II results: Table 14 lists a selection of the QNST-II results. The complete results for this test are detailed in Appendix D.

Explanation of results: the total score is the sum of the scores for the 15 sub-tests. The scores are categorised as severe discrepancy (SD), moderate discrepancy (MD) or normal range (NR). A total score in the SD category means that the individual would have experienced *significant* difficulty with several of the sub-tests. A total score in the MD category is indicative that the pupil experienced *some* difficulty with several of the sub-tests. Finally, pupils who achieved a NR score would have had minimal difficulty with the sub-tests.

Discussion of results: some of the sub-tests were not completed by all of the pupils. Sub-tests 8 (double simultaneous stimulation of hand and cheek) and 10 (arm and leg extension) required physical contact between the test administrator and the subject. These tests were only carried out with the pupils whom the tester decided would not be intimidated by them. Sub-tests 11 (tandem walk) and 12 (stand on one leg) were not conducted with pupils whom the tester had already observed to have an unsteady gait (one of which was in a wheelchair). Finally, many pupils did not want to do task 13 (skip).

Table 14. Selection of QNST-II results

User	Gender	Age	Total score	Category
Primary department				
A	F	8:06	43	MD
B	F	10:08	57	SD
C	F	11:08	46	MD
D	M	7:04	19	MD
E	M	8:06	43	MD
Secondary department				
G	F	13:00	32	MD
H	F	15:00	41	MD
I	F	15:08	27	MD
J	M	15:01	31	MD
K	M	15:04	39	MD
L	M	15:04	40	MD
M	M	16:05	34	MD
W	M	16:00	33	MD
16+ department				
N	F	17:05	40	MD
O	F	18:11	48	MD
P	F	19:00	36	MD
Q	M	17:01	45	MD
R	M	17:10	37	MD
S	M	18:02	21	MD
T	M	18:11	39	MD
U	M	19:05	39	MD

The majority of the user group (20 pupils) achieved a total score within the MD category, with 3 of these pupils scoring close to the NR category. Hence, 20 pupils experience some difficulty with several of the sub-tests. One pupil's total score (user B) was calculated to be within the SD category, with SD scores for sub-tests that assess gross-motor, fine-motor and spatial organisation skills. 7 pupils achieved SD scores for sub-tests 2 and 9. Hence, these pupils experienced significant difficulty with some of the human factors that these tests assess:

- Sub-test 2 – figure recognition and production: skill in controlling fine-motor movement, motor planning and ability to grip
- Sub-test 9 – rapidly reversing repetitive hand movements: motor planning and sequencing, sense of rate, spatial organisation and balance

14 pupils achieved NR scores for sub-test 4 and 15 pupils for sub-test 15. Hence, these pupils were found to have minimal difficulty with the human factors that these tests assess:

- Sub-test 4 – eye-tracking: visual perceptual skills, maturity in motor development and disorders of attention
- Sub-test 15 – behavioural irregularities: disorders of attention and behavioural difficulties

Range of Movement test (ROM test)

This test was devised for this study and was put together using literature obtained from the occupational therapist on the usability team. A copy of this test can be found in Appendix E. This test assesses reach and the active range of upper extremity movement. The pupils' reach ability was assessed by asking them to 'bang' a strategically placed saucepan with a wooden spoon. Table 15 details how the active range of upper extremity movement was assessed.

Table 15. Assessment of upper extremity range of movement

Upper extremity	Assessment task
Shoulder	Throw and catch a ball
Elbow	Wave from elbow; lift a weight action
Wrist	Wave from wrist; bend hands forwards and backwards
Fingers	Press buttons; thumb and finger circle (sub-test 7 on QNST-II)

Results of ROM test: the results of this test, along with the QNST-II results and details from the pupils' educational files (e.g. from physiotherapy reports) are listed in the context report (Appendix F) in the physical abilities section. The data gathered on the physical abilities has been categorised as either fine-motor or gross-motor.

Fine-motor ability

11 pupils were observed to have a good pen grip when writing and drawing (QNST-II), 18 pupils were able to isolate a finger press on a toy telephone (ROM test) and 20 pupils were observed to have good strength. The majority of the user group displayed motor planning difficulties (19 pupils) and poor muscle directing capacity (18 pupils), the latter of which suggests that fine-motor tasks such as writing or crafts may be difficult or time consuming (QNST-II). 10 pupils were observed to have a clumsy pen grip during sub-test 1, entitled 'Hand Skill', of the QNST-II. Finally, 6 pupils were observed to have limited wrist movement (ROM test). Further user group fine-motor data is detailed in Table 16.

Gross-motor ability

20 out of the 21 pupils in the user group were independently mobile (one user had a wheelchair). The ROM test revealed that 15 of the pupils had good reach ability and 11 had good upper extremity movement. The greatest gross-motor difficulties were observed to be with motor planning, balance and co-ordination (QNST-II). Further data on the gross-motor ability of the user group is detailed in Table 16 (note: the numbers in Table 16 represent the number of pupils).

Table 16. A selection of the physical attributes of the user group

Fine-motor ability	Gross-motor ability
Good fine-motor ability • Good pen grip: 11 • Can isolate finger press: 18 • Good strength: 20	Good gross-motor ability • Independently mobile: 20 • Good upper extremity movement: 11 • Good reach ability: 15
Fine-motor difficulties • Clumsy pen grip: 10 • Tight pen grip: 3 • Motor tension: 4 • Slight hand tremor: 3 • Limited wrist movement: 6 • Wrist dip (muscle hypertension): 6 • Weak grip: 1 • Finger dexterity difficulties: 6 • Motor planning difficulties: 19 • Poor muscle directing capacity: 18	Gross-motor difficulties • Unsteady gait: 3 • Uses a walker/Major Buggy: 1 • Cerebral Palsy in legs and right arm: 1 • Bend in spine: 1 • Unsteady arm movement: 2 • Rigid arm: 1 • Can't fully stretch right arm: 1 • Co-ordination: 14 • Motor planning: 18 • Balance: 16

5.3.4 Perceptual ability

Details of the perceptual abilities of the user group were obtained through the QNST-II, a laterality test and the pupils' educational files. Sub-tests on the QNST-II gave details on visual and auditory perceptual skills, sense of rate and rhythm and spatial organisation. The pupils' educational files provided further information on visual and auditory ability.

Laterality test

The Child's Laterality test, which is test 9 on the Aston Index (Newton & Thomson ,1976) was followed to assess each individual's lateral dominance. 8 out of the 10 items on this test were presented to the pupils in the user group. These 8 sub-tests included: write; throw ball; screw lid; deal cards; thread beads; kick ball; telescope and listen test. Each item of the test was presented to the child in turn, and the hand (or eye/ear/foot) which was used to perform the test was observed. Each item was performed twice, to note inconsistencies in laterality. Table 17 details a summary of the results of the laterality test.

Explanation of results: The 'left' column of Table 17 contains the total items performed by the pupil with the left hand (or eye/ear/foot) and the 'right' column, the tasks performed with the right hand (or eye/ear/foot). The 'left and right' column contains the total of items performed once left and once right in the two trials. A maximum score of 8 was given for all items being unilateral (i.e. all right, or all left). Two points were taken off this maximum for each item performed on the opposite side to the most frequent response. One point is taken off for items performed once left and once right in the two trials. Hence, a low score is indicative of poor lateral dominance (mixed laterality).

Table 17. Summary of laterality test results

User	Left	Right	Left + right	Score	Dominance
Primary department					
A	0	6	1	7	Right
B	0	5	2	6	Right
C	2	5	\	4	Mixed
D	0	4	\	8	Right
E	3	5	\	2	Mixed
Secondary department					
G	3	5	\	2	Mixed
H	0	8	\	8	Right
I	1	7	\	6	Right
J	6	2	\	4	Mixed
K	6	2	\	4	Mixed
L	4	4	\	0	Mixed
M	4	4	\	0	Mixed
W	1	7	\	6	Right
16+ department					
N	4	3	\	2	Mixed
O	2	5	\	4	Mixed
P	3	4	1	1	Mixed
Q	3	3	1	1	Mixed
R	4	4	\	0	Mixed
S	3	5	\	2	Mixed
T	2	4	1	3	Mixed
U	6	1	\	6	Left

Discussion of results: As can be seen in Table 17, 14 pupils were found to have mixed laterality, 6 pupils had right lateral dominance and only 1 pupil (U) had left lateral dominance. Mixed laterality can cause difficulties in both the language arts area (in terms of orientation and visual tracking) and in the math/science area (in terms of directionality, orientation, spatial awareness and visual discrimination). Difficulties may also occur in the area of hand, eye and body co-ordination (Lannen, 2002)

Perceptual ability data

The perceptual ability data gathered from the various sources is listed in the context report (see Appendix F). This data has been categorised as visual, auditory or visual-motor perception. Table 18 lists a selection of this perceptual data (note: the numbers in Table 18 represent the number of pupils).

Table 18. Selection of perceptual data

Visual perception
• Wears glasses: 7 • Horizontal/vertical eye jerkiness: 4
Auditory perception
• Auditory processing difficulties: 14 • Hearing impaired (left ear): 1 • Hypersensitive to loud noise: 2
Visual-motor perception difficulties
• Spatial awareness: 17 • Directionality: 15 • Ordering and sequencing: 11 • Mixed laterality: 13

5.3.5 Communication

The communication data was obtained from the annual monitoring forms in the pupils' educational files. This research revealed that the majority of the user group used Makaton signing, in order to communicate with teachers and other pupils. As previously stated, Makaton is a language system for people with a wide range of generic learning difficulties. There is a wide variety of communicative ability within the user group. 3 of the pupils had quite good verbal communication, whereas others are limited to signs, gestures and some vocalising. Table 19 lists all the data obtained on the user group communication (note: the numbers in Table 19 represent the number of pupils).

Table 19. Communicative ability of the user group

• Use Makaton signing: 21 • Quite good verbal communication: 3 • Short sentences: 9 • One or two word speech: 6 • Signs, gestures and some vocalising: 3 • Stutter: 2 • Quiet speech: 5 • Repetitive speech: 1 • Signing difficult due to fine-motor dexterity: 3 • Computerised voice aid: 2

5.3.6 Behaviour and motivations

User group behaviour was observed during the QNST-II and other assessment tests. Further data was obtained from the pupils' educational files. The main points to note about behaviour are: 5 pupils are distractible; 6 pupils required encouragement to complete tasks and 13 pupils displayed anxiety during assessment.

During the course of the various assessment tests, the pupils were asked about their interests, including job interests. Further details of what motivates the individuals were obtained from the pupils' education files. The complete list of user group behaviours and interests identified are detailed in the context report (Appendix F).

5.3.7 Usability team feedback

A usability team meeting was held to review the user analysis data gathered and to allow any important contextual issues to be raised. The following professionals were present at this meeting: design engineer; HCI expert; psychologist (from the department of learning disabilities at Nottingham University) and a human-factors expert. Table 20 details a selection of the feedback from this meeting.

Table 20. Selection of feedback from usability team meeting

• Wrist dip – support the arm in a comfortable position
• Accessibility – pull out table to rest the device on for those users in special chairs
• Perhaps design to extend the abilities of the user group
• Attention – the system should attain the student's attention
• Encouragement – the system should be success orientated, helping to build confidence
• Black box - allows different input devices to be used to control the same software
• It may be possible to develop a navigation tutor, embodied in the software

5.4 TASK ANALYSIS

The objective of task analysis is to develop a clear understanding of what the product must do, so that the product can be designed to fit its' purpose. Three tools were utilised for the VE input device task analysis: the UCA context questionnaire; a hierarchical task analysis and the USERfit Activity Analysis. Before using these tools, research was conducted on virtual environment (VE) and 3D game tasks.

5.4.1 VE tasks

The VE research involved using the joystick and mouse to control a selection of the VEs that were designed for users with learning difficulties. The VEs studied were the virtual factory, café and supermarket. Whilst using each VE, the following details were recorded: user tasks; device tasks; difficulties experienced and development ideas. The data noted for the virtual factory was as follows:

- User tasks: listen to instructions; read instructions
- Navigation: primary movements – forward/back and turn left/right; secondary movements – look up/down and side-step
- Interaction: move cursor over VE object; initiate interaction
- Difficulties: navigation – some spaces restrict movement; interaction – some objects slightly too small
- Future development: interaction – pick up VE object (appears in foreground of screen) and place (in desired position); navigation – tactile feedback, i.e. ability to 'feel' the VE walls

5.4.2 3D game tasks

For 3D game research the input device tasks for Cool Boarders, Courier Crisis and Grand Turismo 2 were analysed. As with VE control, these games have primary and secondary device tasks. The primary tasks included accelerate, left/right turn and brake. The secondary functions were much more varied as they were specific to the game being controlled. For example, the secondary functions for Cool Boarders are hard turn, grab and jump, whereas the secondary functions for Grand Turismo 2 are hand brake, reverse and shift up/down a gear. Based on this research, the following idea for VE control emerged: 'ability to adjust the secondary navigation functions, to increase compatibility with 3D software'.

5.4.3 UCA context questionnaire

The task characteristic section of the context questionnaire requested information such as task frequency, task duration and task dependencies. These details were added to the context report (see Appendix F). Table 21 lists a selection of the task characteristics.

Table 21. Selection of task characteristics (context questionnaire)

Question	Answer
Task frequency	1 session per week or fortnight (for each pupil)
Task duration	~ 30 minutes (dependent on pupil's attention span)
Task dependencies	Computer software, processor and monitor; teacher/carer assistance
Linked tasks	VE may relate to class work or 2D software task

5.4.4 Hierarchical task analysis

One approach to task analysis is the hierarchical task analysis. In this process the primary tasks are broken down into subtasks and consequently the subtasks are further broken down (Dumas, 1999). Figure 23 shows the hierarchical task analysis for VE control.

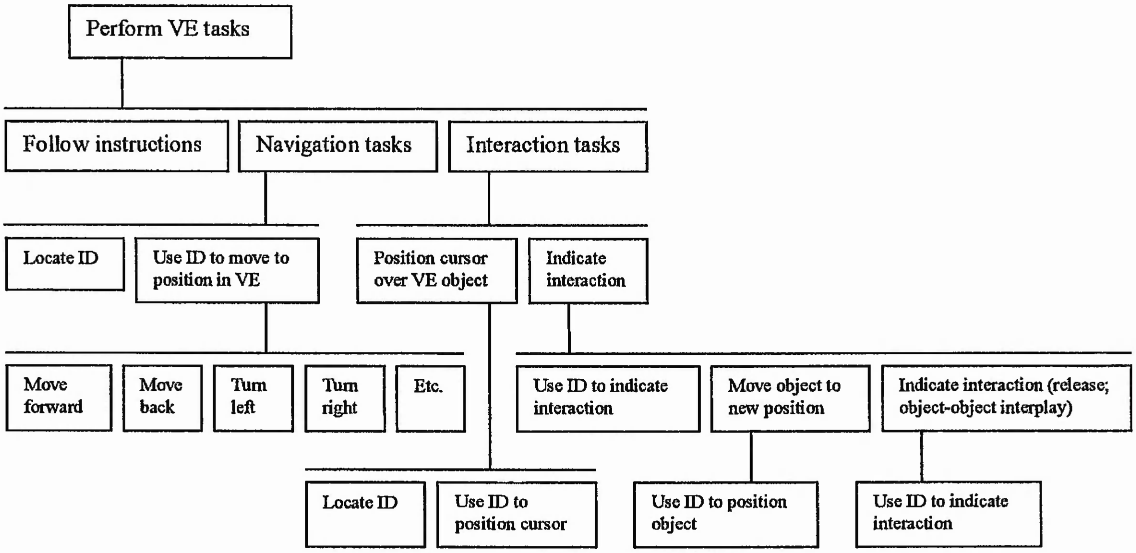


Figure 23. Hierarchical task analysis for VE control

5.4.5 Activity Analysis

The Activity Analysis (AA), from the USERfit methodology, comprises of 3 tools: Stakeholder Scenario List (AA1); Activity Elements Summary (AA2) and Requirements Summary (AA3). Only the first 2 of these tools have been utilised for this study. The Stakeholder Scenario List (AA1) summarises the main activities carried out by each relevant stakeholder group. In this study, the end-users are the stakeholder group that have been focused on. Hence, for AA1, the main activities that the end-users would carry out with the input device were summarised as follows:

- Navigation within a VE
- Interaction with objects within a VE

The Activity Elements Summary (AA2) involved listing all the elements that make up the main activities. Table 22 details the AA2 performed on VE control for users with learning difficulties.

Table 22. Activity Elements Summary (part of USERfit methodology)

Navigation within a VE	Interaction with objects within a VE
• Locate workstation • Sit comfortably at workstation • Locate navigation device • Establish contact with navigation device • Decide on desired movement in VE • Use device to cause desired movement in VE • Stop action with device, to stop movement in VE	• Locate object/item to interact with or select • Locate interaction device • Establish contact with interaction device • Use device to move cursor over VE object/item • Use device to select/interact with VE object/item

5.5 ENVIRONMENT ANALYSIS

This analysis involved research into the environment in which the VE system would be used. The main tool used for the environment analysis was the UCA context questionnaire. This questionnaire required details on the organisational, technical and physical factors of the environment. The teacher questionnaire was devised to obtain some of the task and environment data from the teachers at the Shepherd School. A copy of this questionnaire can be found in Appendix E, along with the feedback gained. Table 23 lists a selection of the questions and answers from the teacher questionnaire.

Table 23. Teacher questionnaire – selection of questions and answers

Question	Answer
On computer work, is it better for pupils to work alone or in small groups?	Alone
If a VE system was available, where would you prefer it to be used: in the classroom or in a different room (please specify)?	In the classroom
If the VE system was used in the classroom, how much teacher/carer assistance would be available?	1-to-1 for 10/15 minutes

Table 24. Selection of environment analysis data

Question	Answer
Organisational environment	
Group working	Work alone or in small groups (2 to 3); collaborative VEs
Assistance	Teacher/carer assistance may be required
Interruptions	Other pupils may distract the user
Technical environment	
Hardware required to run the product	Computer processor and monitor; internet (collaborative VEs)
Software required to run the product	Windows and VE platform
Physical environment	
Auditory conditions	Noise of teachers, pupils and class equipment
Visual environment	Suitable for computer use
Location of workplace	In classroom, computer room or quiet room
Product environment	
Training needs	VE or manual to learn how to use input device(s)
Documentation	Instructions to set-up and maintain the system
Decommission	Dispose of as domestic waste

The data gathered using the teacher questionnaire helped to complete the relevant parts of the UCA context questionnaire. The Product Environment (PE) tool from the USERfit methodology was used to compliment the UCA data. The PE tool considers the wider implications of how the product will be supported. The context report contains all of the VE system environment data that was collected. Table 24 details a selection of this environment analysis data.

6. Specify the User and Organisational Requirements

Specifying the user and organisational requirements is the second step in the multi-disciplinary design methodology. The final objective of this step is to produce a product design specification, which lists all the requirements necessary to select or design a usable product. In order to reach the final objective, the following steps were conducted:

- Contextual requirements: requirement elicitation from contextual information (user, task and environment data)
- Requirement research: British Standards and HCI requirements
- Product analysis: specify how the requirements can be met through specific product attributes

6.1 CONTEXTUAL REQUIREMENTS

This step builds on the context of use data (user, task and environment data) and involves capturing the user-centred requirements for the VE input system. In the USERfit methodology, the term 'functional implications' is used instead of product requirements and it is stated that the functional implication is the bearing that each attribute (user, task or environment) may have on the design of the product (Poulson, 1996).

6.1.1 User analysis questionnaire

The user analysis questionnaire contained details of the physical and perceptual characteristics, behavioural data and certain conditions (e.g. epilepsy) of the user group. This questionnaire was sent to an occupational therapist, a physiotherapist and an educational psychologist to gain their expert opinion of how the VE input device should be designed to accommodate for the user characteristics. The completed questionnaires can be found in Appendix G, along with a comprehensive requirement feedback document. The recommended device requirements were added to the requirement specification (see Appendix H), which lists all of the requirements that have been extrapolated from the contextual data. A selection of the contextual requirements is listed in Table 25.

Table 25. Contextual requirements

User analysis data (feedback from questionnaire)	Requirement
Hypotonic	Provides muscle support (arm/hand)
Motor-planning difficulties	Provides visual cues to function
Co-ordination difficulties	Slots/guides to assist user action
Ordering and sequencing difficulties	Minimal user input for task completion
Distractible	Motivational to use (motivates user)
Task analysis data	**Requirement**
Establish contact with navigation device	Ergonomic design of user interface
Use device to interact with VE objects	Buttons – easy to operate
Task duration: ~ 30 minutes	Durable
Mental demands: how to achieve navigation & interaction	Adaptable to user's cognitive ability
Environment analysis data	**Requirement**
Interruptions: other pupils may distract user	Workstation helps focus attention on VE
Software required: VE platform	Compatible with VE platform

6.2 REQUIREMENTS RESEARCH

6.2.1 British Standards

It is important that the VE input system conforms to the requirements specified by the relevant British (or European) Standards. The most relevant standard is:

- Ergonomic requirements for office work with visual display terminals (VDTs) – Part 9: Requirements for non-keyboard input devices (ISO 9241-9:2000)

Parts 5 and 6 of the same standard were also referred to. These standards are defined as:

- Part 5: Workstation layout and postural requirements (ISO 9241-5:1999)
- Part 6: Guidance on the work environment (ISO 9241-6: 2000)

Section 4 of ISO 9241-9 (requirements for non-keyboard input devices) lists the basic ergonomic principles that apply to all input devices. These principles include obviousness, predictability, consistency, compatibility, feedback, satisfaction, non-interference, grip-surface and device access. Some of these principles had already been covered in the requirement specification. For example, the definition of compatibility is:

- An input device is user compatible when its design accommodates the anthropometric characteristics and biomechanical capabilities of the intended users.

Hence, compatibility was already covered by 'ergonomic design of user interface' and requirements that relate to physical ability, such as 'detects range of motion'. Any of the ergonomic principles that were not already included in the requirement specification were added.

Section 6 of ISO 9241-9 is based on section 4 (the ergonomic principles) and states the design requirements and recommendations, which are general to all non-keyboard input devices. Any of these requirements that were not already covered by the requirement specification were added. Similarly, the workstation and work environment standards were examined for further important requirements. Table 26 details a selection of the European Standard requirements that were added to the requirement specification.

Table 26. Selection of European Standard requirements

Design requirement	Note from British Standard (ISO 9241-9)
Operation is obvious /clear /predicatable	The intended use of an appropriately designed input device is either obvious or easily discovered
Does not interfere with own use	An appropriately designed input device does not interfere with its own use, i.e. cables not interfere with device control
Ensures good posture	Upper extremity posture – operated without requiring undue deviations from neutral positions
Appropriate texture	Grasp stability – grip surface should be of sufficient size, shape and texture to prevent slipping
Accessible	Access – the design of an input device should allow it to be located and be accessible within the user's reach envelope
Design requirement	**Note from British Standard (ISO 9241-5)**
Encourage postural change	Postural change – The workplace organisation, the task and the furniture should encourage voluntary postural changes
Maintainable	Maintainability – access for maintenance can be accomplished easily
Safe to use	Safety and stability aspects of workstations - the work surface, loaded with intended equipment, should not tip over if a person leans on any side or sits on the edge
Adequate seating	Work chair, main considerations: easy to maintain and change posture; provides support for the spine; sufficient surface friction to prevent sliding off, etc

6.2.2 HCI

It was important to ensure that the principles of interface design were covered by the requirement specification. These principles, as listed in Table 8, Chapter 4, are naturalness, consistency, relevance, supportiveness and flexibility. An examination of the requirement specification showed that these principles were already covered by the contextual and European Standard requirements. Table 27 details the requirements specified to satisfy the principles of interface design. Additionally, HCI literature states that the computer interface must help the user to acquire an accurate mental model of the application (Faulkner, 1998). Hence, the device requirement 'understandable design model' was added to the requirement specification to satisfy this HCI design factor.

Table 27. Requirements to meet the principles of interface design

Principle	Requirement
Naturalness	Operation is obvious /clear /predictable
Consistency	Operation is consistent, no guessing required
Relevance	Minimal user input for task completion; only necessary functions are available
Supportiveness	Adaptable to user's cognitive ability; step-by-step training to use is provided; provides effective feedback
Flexibility	Adaptable to user's cognitive and physical ability; user action can be assisted

6.3 PRODUCT ANALYSIS

The product analysis is one of the USERfit methodology's 9 summary tools. This tool is concerned with the functional aspects of the proposed product and involves describing how each design requirement can be achieved through specific product attributes. With reference to the requirements listed in Table 25, the requirement 'provides visual cues to function' could be met by the device attribute 'form indicates function'. Employing this attribute would mean that the shape of the proposed product would indicate to the user how VE navigation and interaction is achieved. The complete list of device attributes is listed in the design specification, which can be found in Appendix H. Table 28 details the device attributes that were specified to meet the design requirements in Table 25.

Table 28. Selection of device attributes

User analysis requirement	Device attribute
Provides muscle support (arm/hand)	Ergonomic design of muscle support
Provides visual cues to function	Form indicates function (navigation and interaction)
Slots/guides to assist user action	Slots/guides to assist user action
Minimal user input for task completion	One user action = one VE function
Motivational to use (motivates user)	Accepts enthusiastic operation; modern style
Task analysis requirement	**Device attribute**
Ergonomic design of user interface	Ergonomic design (users 7 – 19, anthropometric data)
Buttons – easy to operate	Buttons – appropriate size and position
Durable	Robust mechanical/electronic design; durable materials
Adaptable to user's cognitive ability	Modifiable operation difficulty
Environment analysis requirement	**Device attribute**
Workstation helps focus attention on VE	Channels attentions to VE; built in carrels
Compatible with VE platform	Could mimic joystick and mouse input

6.4 DESIGN SPECIFICATION

Design specification categories

In order to make the design specification more structured and easier to follow, the design requirements were sorted into categories, including: product appearance; ergonomic design; interface and functional assistance; cognitive factors; physical factors; computer input and workstation (see design specification in Appendix H).

Basic, performance and excitement needs

According to the Kano model of quality (named after its inventor, Dr. Noriaki Kano) user satisfaction with a new product can be broken down into three component parts: basic, performance and excitement (Baxter, 1995). These factors of user satisfaction are defined as follows:

- *Basic*: unspoken features, typical of competing products, failure to achieve will result in user dissatisfaction
- *Performance*: spoken needs and wishes, generally additive in producing user satisfaction, low achievement can give rise to dissatisfaction
- *Excitement*: unspoken, latent user needs that satisfy genuine needs, failure to achieve does not give dissatisfaction

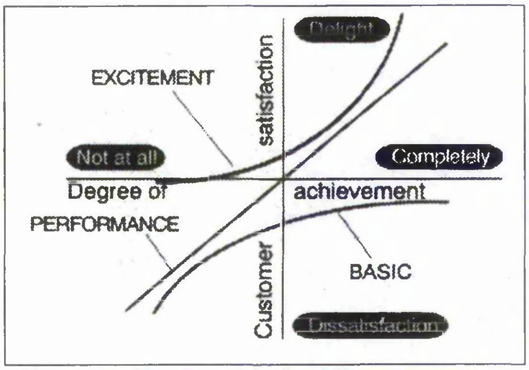


Figure 24. Kano model of quality

Good product planning incorporates basic, performance and excitement factors into the design specification and aims for user delight by achieving all these factors (see Figure 24). A decision was made for each device attribute, in the design specification, concerning which satisfaction category they fitted into, and the decision was noted in brackets after each attribute: (b) for basic need; (p) for performance need and (e) for excitement need (see design specification in Appendix H).

Further design specification headings

There are further important aspects of a product's design, which were not discovered through the contextual research (user, task and environment). These aspects come under the following headings: market requirements (performance and target price); production requirements; life in service requirements and conformance requirements. These headings cover four important determinants of product success: will it sell; will it work; can it be made and does it comply with legal and commercial obligations (Baxter, 1995). These design aspects were added to the design specification for the VE input system.

6.4.1 Usability team feedback

A copy of the final requirement specification and the design specification was sent to each member of the usability team to obtain their guidance concerning any requirements or device attributes that they thought should be added or subtracted. The feedback given was very positive, with only the following recommendation: when designing to meet the device attribute 'ergonomic design for age 7 – 19', it is important to be aware that the user group may be smaller than their peer group, in terms of anthropometric details.

6.5 TECHNOLOGY REVIEW

The technology review is the third step in the multi-disciplinary design methodology. The aim of this review is to identify any existing computer input devices that meet the requirements in the design specification or could be adapted to meet the requirements. If no suitable devices are identified, the next step in the methodology is carried out: concept and prototype design.

6.5.1 Research areas

The following computer interface areas were reviewed, with reference to the design specification: assistive computer input devices; general computer input devices; virtual reality and gaming devices. The Internet provided a rich source of information for all areas of research. The assistive technology devices were identified from an Internet site entitled 'Adaptive Computer Products' (www.makoa/computers.htm). This site was frequently updated and gave links to a vast range of assistive technology, including mouse alternatives, eye-tracking devices and head-tracking devices. A visit to PC world provided further research into general computer input devices and gaming devices.

6.5.2 Results

Several devices, which are pictured in Figure 25, were found to possess a few of the device attributes in some of the design specification categories. For the *product appearance* category the KidTrac fits 'modern style, attractive colours' and the Kidsball fits 'style 1: toy like, fun'. For *ergonomics design*, the Anir Ergonomic Mouse has been designed to help avoid repetitive strain injury (RSI), to partly satisfy 'conforms to health and safety standards'. The FireStorm is a game console, which satisfies 'form indicates interface' and 'haptic sensation with user action', which are *interface and function assistance* attributes. For *cognitive factors*, the PANTHER XL is a gaming control device, which indicates how navigation and interaction functions could be in one device without conflicting. For *physical factors*, the Roller Joystick 'provides assistance to use actions', with its latching drag feature and is of a 'robust construction'.

KidTrac (MicroSpeed)

KidsBall (Keytools)

Anir Ergonomic mouse (Keytools)

FireStorm (ThrustMaster)

PANTHER XL (Mad Catz)

Roller Joystick (Penny & Giles)

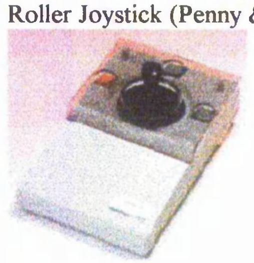


Figure 25. Input devices, which satisfy some of the device attributes

The Tilting Games Pad was found to be the 'closest concept', see Figure 26a, matching a significant number of the device attributes listed in the design specification. Visually, it would appeal to the user group, with its 'modern style, attractive colours'. The device is worn by adorning a glove, hence the 'form indicates the interface' (*interface and function assistance*). The user is required to tilt or wave their hand for the software to react, which suggests that the *cognitive factor* 'movement in VE same as user action' could be fulfilled. However, there are further *cognitive factors* that would be difficult to meet with this glove device. For example, 'movements are specific' would be difficult to achieve if the glove is moved around in free space. It might be necessary to have a navigation reference to enable more specific movements (see Figure 26b). Additionally, as the Tilting Games Pad is worn on the hand, if the user is distracted and moves his/her hand off task, he/she could lose their place within the VE.

a. Tilting Games Pad

b. navigation reference

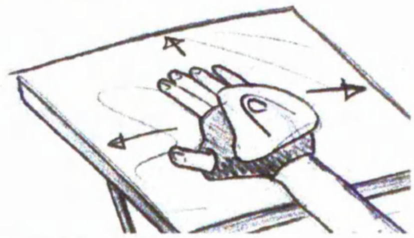
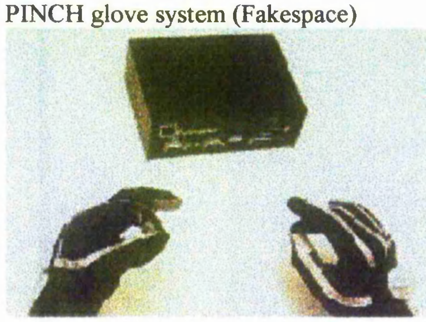


Figure 26. Closest concept - The Tilting Games Pad (Keytools)

Further inspiring technology was identified from the virtual reality review, including Gypsy, the PINCH glove system and CAVE C04 (shown in Figure 27). Gypsy is an exoskeleton made of lightweight aluminium rods that follow the motion of the performer's bones and could fit the device attribute 'movement in VE same as user action'. The PINCH glove system provides a reliable and low-cost method of recognising natural gestures. Hence, this system could be referred to if the *computer input* attribute 'gestures can be used for input' is pursued. Finally, by using special 'stereoscopic' glasses inside a CAVE C04, the user is fully immersed. This type of environment could offer an exciting experience for people with learning difficulties. However, this research project is focused on desktop VEs, which, as previously stated, are currently the preferred set-up for this user population.

Gypsy (Meta Motion)

PINCH glove system (Fakespace)



CAVE C04 (Fakespace)

Figure 27. Inspiring technology from the virtual reality review

6.6.3 Discussion and conclusion

Several devices were found to satisfy a few of the device attributes from certain requirement categories, with some devices meeting attributes across two or three categories. However, considerable adaptation would be necessary for these devices to meet all of the device attributes in the design specification. Although the Tilting Games Pad was found to meet a significant number of the device attributes, there were also many that it didn't satisfy, such as the *cognitive factor* 'movements are specific'. It was also stated that this device could cause navigation confusion, if the user is distracted and performs off task hand movements. Hence, as the technology review presented no input device to sufficiently satisfy the design specification or one that could be easily adapted to do so, it was necessary to progress to concept and prototype design.

An additional benefit of the technology review was that it provided a great source of ideas for concept design of certain device attributes, with the exciting virtual reality technology helping to inspire innovation.

7. Concept and prototype design

The product design methods described by Baxter (1995), for concept and prototype design, were utilised for this stage of the design process. The design specification (see Appendix H) was used to guide concept and hence prototype development.

7.1 ERGONOMICS RESEARCH

Control design

The design of handles and tools was researched to help with the design of usable concepts. The details below on guidelines for handle design and the biomechanics of tool design have been taken from 3 ergonomic sources: Bodyspace (Pheasant, 1996), Fitting the task to the human (Kroemer and Grandjean 1997) and Cumulative trauma disorders (Erdil, 1996).

Guidelines for handle design:

- Form-fitting handles should be matched carefully with the user population
- All sharp edges or other surface features that cause pressure spots when gripped should be eliminated, i.e. finger shaping – unless designed with anthropometric factors in mind
- Handles and grips should be cylindrical or oval and effectiveness increases with thickness (diameter) up to 30-40mm
- Handles should be at least 100mm long (115 mm– 120 mm is preferable)
- Rectangular or polyhedral sections will give greater purchase, but not as comfortable
- Surface quality: not too smooth to be slippery; not too rough to be abrasive; rubber becomes tacky

Biomechanics of tool design:

- A torque exerted perpendicularly is very much greater than that of a handle turning about its own axis
- Grasping power greatest when hand in neutral position or slightly bent upwards (extended)
- Grasping force 4 times greater clasping with whole hand than holding with the fingertips
- Handles that require a power grip are less fatiguing (see Figure 28a)
- Horizontal movements are easier to control than vertical movements
- Keep wrist close to neutral position – avoid 'wear and tear' on tendons, and development of work related musculoskeletal disorders

- When force applied by hand, wrist kept straight and elbow bent at right angle
- When wrist in neutral position, the long axis of a cylindrical handle, makes an angle of 100-110 degrees to the axis of the forearm (see Figure 28b)
- Hand should by kept in line with forearms as much as possible
- Movement of forearms and hands at most skilful, if take place within an arc of 45-50 degrees to each side

a.

b.

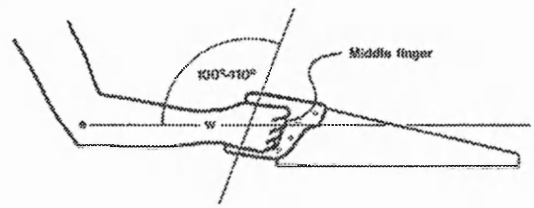


Figure 28. a – power grip; b – neutral position of the wrist (from Pheasant, 1996)

Cumulative trauma disorders

This is an important area of research to ensure long term usability of the VE input device. Cumulative trauma disorders (CTDs) can result when the musculoskeletal system is overloaded by a succession of small traumas (microtraumas). One by one these traumas do not injure, but the cumulative effect can lead to overexertion (Kroemer and Grandjean 1997). The following details on handle design for preventing CTDs and movements that contribute to stress on tendons and nerves of hand, is taken from a book entitled 'Cumulative trauma disorders' (Erdil, 1996).

Handle design for preventing CTDs:

- Avoid high contact forces and static loading
- Avoid extreme or awkward joint positions
- Avoiding repetitive finger action

Movements that contribute to stress on tendons and nerves of hand:

- Wrist deviation
- Wrist flexion or extension
- Extremes of elbow flexion
- Extremes of shoulder abduction

There are two kinds of muscular effort: dynamic (motion) and static (posture). With dynamic effort, the muscle length changes, often rhythmically. Static effort is a prolonged state of contraction of muscles. Muscles fatigue quickly in static efforts and hence, as stated in handle design, static loading should be avoided (Kroemer and Grandjean 1997). Some of the movements that should be avoided are depicted in Figure 29.

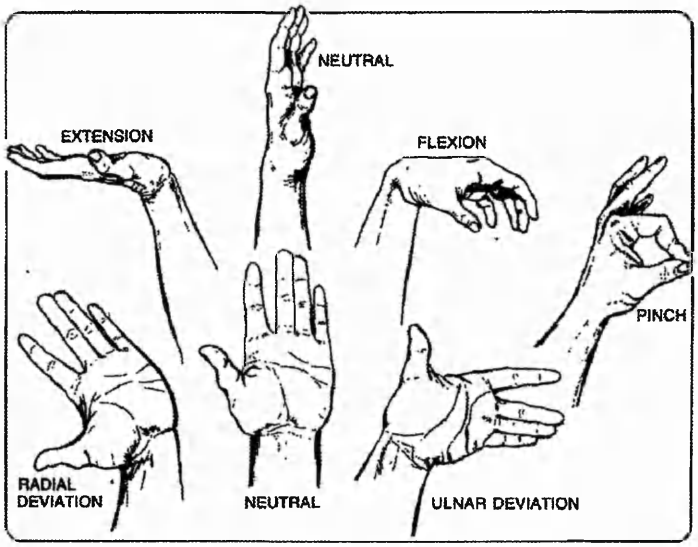


Figure 29. Hand and wrist postures (from Pheasant, 1996)

7.2 CONCEPT DESIGN

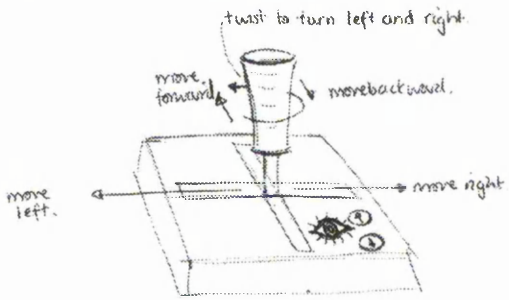
The aim of concept design is to produce design principles for the new product. These principles should be sufficient to satisfy the requirements listed in the design specification and to differentiate the product from others on the market. Concept design sets about producing a set of functional principles for how the product will work and a set of styling principles for the way it will look. The greatest creativity is required in the first stage of concept design, *idea generation*, in which many concepts are generated (Baxter, 1995).

7.2.1 Explore logical solutions

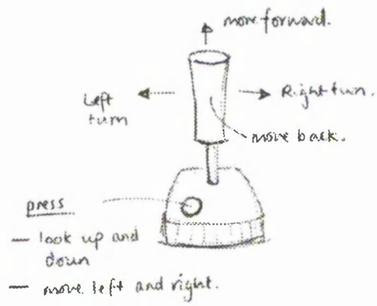
Firstly, a visual design specification was sketched to inspire the logical design ideas (see Appendix I). Many of the design requirements were then explored through further sketching (see sketchbook 1 in Appendix I). A selection of these sketches and the requirements they meet are shown in Figure 30.

Colour & symbol cues to interface

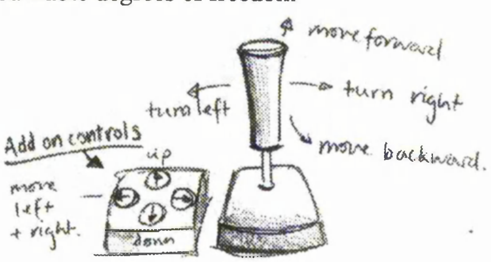
Movement in VE same as user action



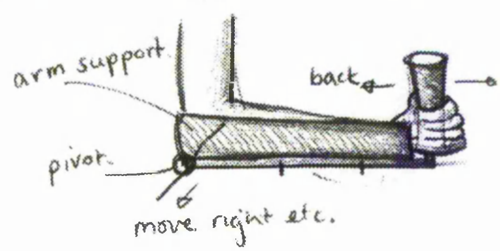
No excess functions accessible



Modifiable degrees of freedom



Support: ergonomic design of muscle support



Navigation & interaction functions in one device

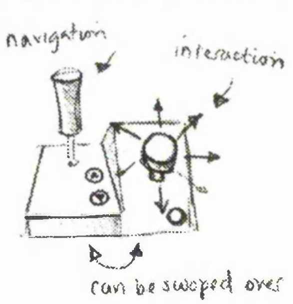
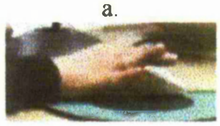


Figure 30. Selection of initial sketches and the design requirements they meet

One of the interface requirements, listed in the design specification, is 'can be operated without gripping the device'. This requirement would benefit users who are unable to grip. It was decided that the users' grip abilities should be examined again to ensure that this requirement was necessary. Grip details were available from sub-test 1 (hand skill) on the QNST-II and the video analysis data (input device evaluation). This information showed that all the users are able to grip. However, the difficulties that need to be accounted for, with interface design, include a clumsy grip; a raised in an unusual position (Figure 31a); a weak grip and a two-handed grip (Figure 31b). From this study the decision was made to amend the design specification, with two options for the interface solution: 'use simple grip for interface (accounting for grip difficulties)' or 'can be operated without gripping the device'.

a.



b.

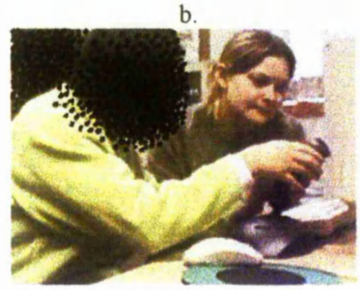


Figure 31. a – finger raised; b – two-handed grip

7.2.2 Product research

Sketchbook 2: this sketchbook, which can be found in Appendix I, details the product research conducted

Shop visits

The following shops were visited for product research: Boots, Mothercare, PC world, Curries, Sainsbury's and Sainsbury's Homebase. The main information gained from these visits was about grips, handles, materials and product form. The baby/toddler feeding products were examined in Boots and Mothercare to identify simple and comfortable grips (see Figure 32). In these feeding products the following attributes were used to assist with gripping:

- Finger and thumb rests
- Contours to fit shape of hand
- Ridges
- Non-slip, soft material

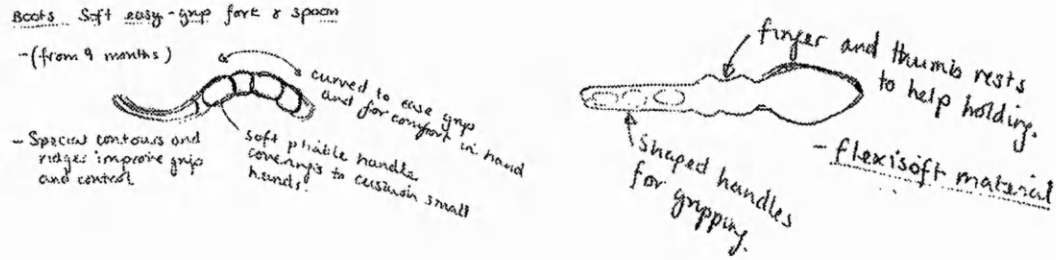


Figure 32. Product research in Boots

Similar attributes were identified to assist the gripping of joysticks from a visit to PC world. For example, many of the mouse products and joysticks are contoured to fit the hand, in order to increase comfort (see Figure 33). Whilst visiting PC world, the Strategic Commander, a gaming device, was discovered (Figure 33). This was an exciting find, as it boasted 'direct mapping' as one of its unique features. This new device was used to inspire concept ideas to meet the design requirement 'movement in VE same as user action'. Irons and kettles were the main source of design inspiration in Curries. The handles on these products detailed the same features, as the feeding products from Boots, to assist with gripping. The new inspiration gained in this shop was for product styling: using clear coloured plastic alongside opaque plastic (see Figure 34)

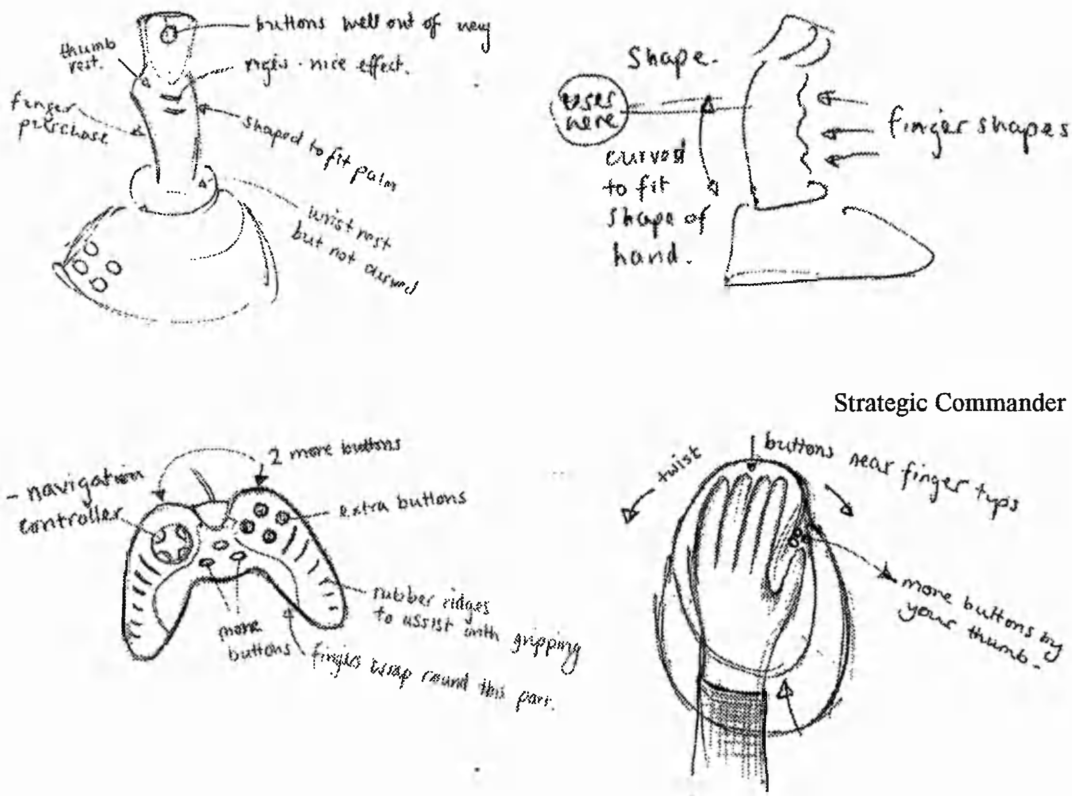
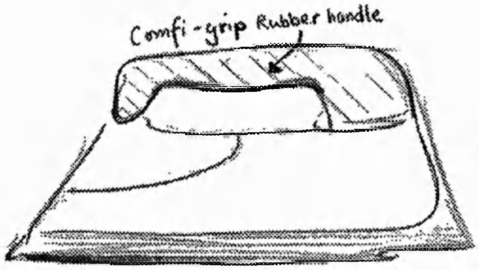


Figure 33. Product research in PC world



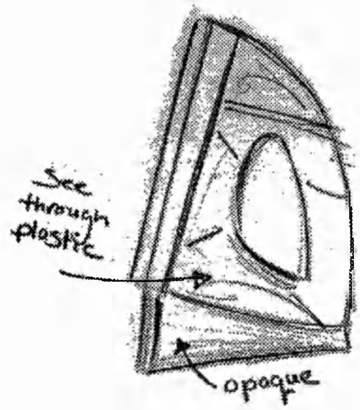


Figure 34. Product research in Curries

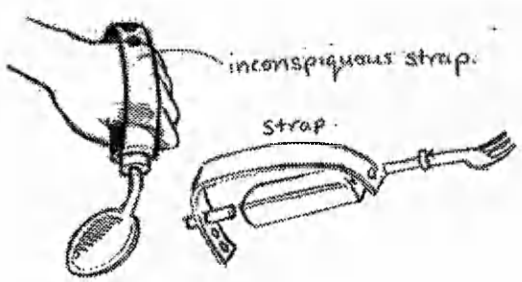
Catalogue research and technology review

The Rifton and Smith & Nephew catalogues were reviewed. As well as showing similar attributes for a comfortable, assisted grip, these catalogues gave inspiration for the following design requirements 'support: ergonomic design of muscle support' and 'can be operated without gripping the device' (see Figure 35a & b). Finally, the Keytools catalogue and the products identified in the technology review were examined for further concept inspiration. This research gave ideas for muscle support, operating without gripping and function (see Figure 36).

Ergonomic design of muscle support

Figure 35a. Product research from the Rifton and Smith & Nephew catalogues

Assistance in gripping the device



Can be operated without gripping the device

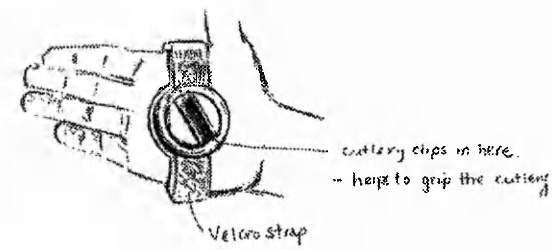
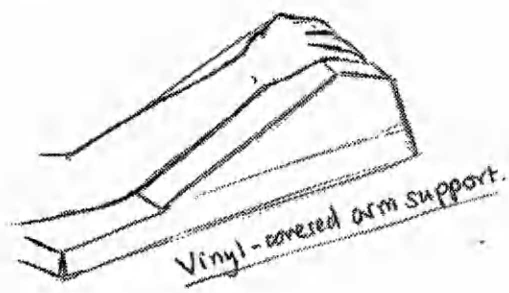
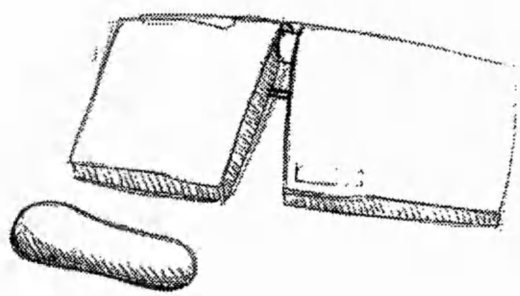


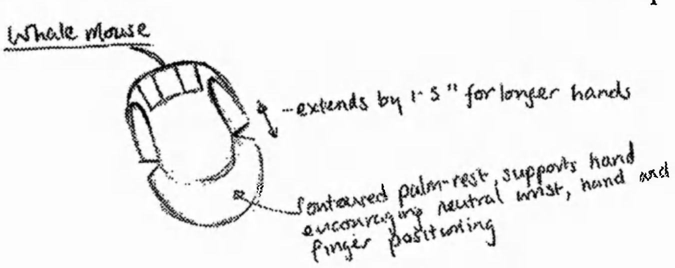
Figure 35b. Product research from the Rifton and Smith & Nephew catalogues

Ergonomic design of muscle support





Functional ideas



Can be operated without gripping the device

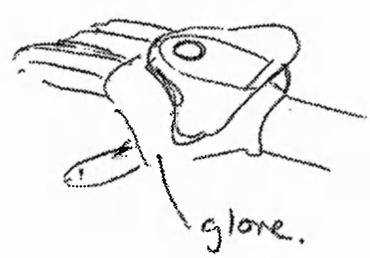


Figure 36. Product research from the Keytools catalogue and technology review

7.2.3 Lateral thinking

Analogies and clichés were used to digress from the obvious solutions to the design problem by changing the designer's perspective and freeing up thinking. When using analogies the designer is encouraged to think of the essence of the problem in abstract terms (Baxter, 1995). The essence of the VE input system is 'navigation' and 'interaction'. Figure 37a shows a selection of the navigation analogies and concept ideas and Figure 37b shows a selection of the interaction analogies and concept ideas.

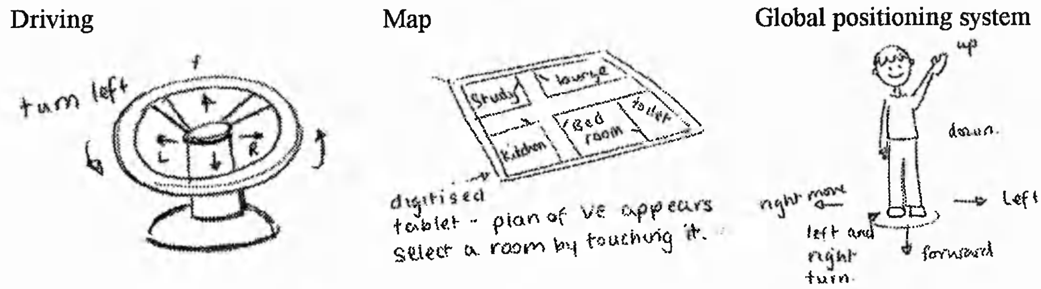


Figure 37a. Navigation analogies and concept ideas

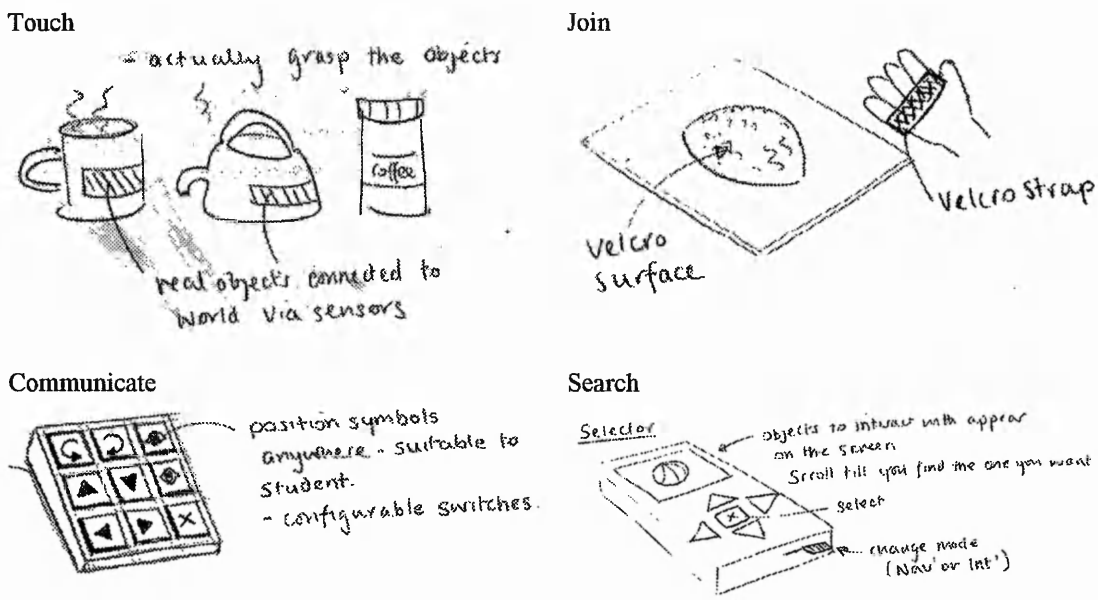


Figure 37b. Interaction analogies and concept ideas

7.2.4 Collective notebook

This method, outlined by Baxter (1995) is used to collect concept ideas from other people. A letter was sent to each member of the usability team, before commencing idea generation, with a copy of the design specification and details of some concept generation methods for inspiration. Table 29 lists a selection of the ideas that were received from the usability team and some of these concepts are depicted in Figure 38.

Table 29. Selection of ideas from the usability team

Concept	Description
Steering wheel with extended steering column	Turn left/right with steering wheel; press button in middle to go forward; push wheel forward and back like a joystick to move up/down, flying it like a plane
Motor cycle handlebars	Handle bars control left/right movement; twist grip on one handlebar controls forward; brake grip on other handlebar slows down; push handlebars forward and back to dive and climb
Voice and joystick	A joystick controls 3D movement with voice recognition for up/down
Pressure sphere	A sphere mounted on a vertical column; user uses pressure to indicate direction of movement in 3D; pressure applied could indicate speed
Roller ball and plunger	User uses two hands to control large coloured roller ball for primary navigation; two buttons either side of ball for left/right move; push/pull plunger handle alongside controls down/up
Musical movement	Wind instrument – where different notes control the functions
3D abacus	User moved 3 balls (mounted in orthogonal set up) along wires to indicate direction of movement
Driving instructor	Dual control devices for teacher and learner; tutor able to guide learner

Steering wheel Motorcycle handlebars Driving instructor

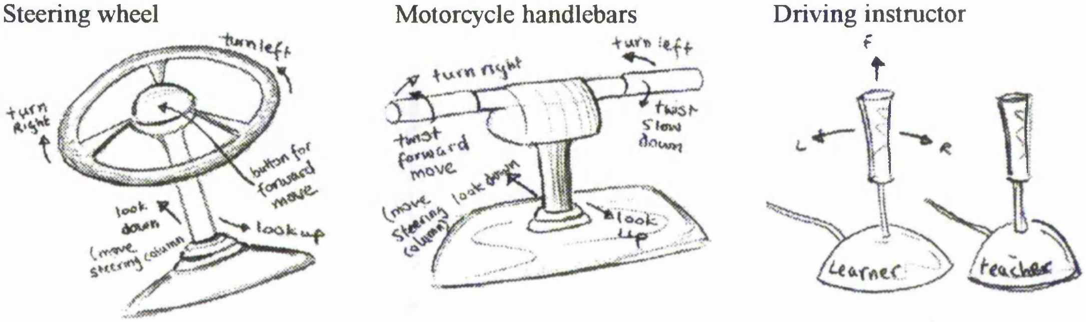


Figure 38. Selection of ideas from the usability team

7.2.5 Theme board

A theme board was put together with images of products that have the desired styling theme for the product under development (see Figure 39). The theme board is used to explore styling features, which have been successful, and to inspire product styling (Baxter, 1995).

Figure 39. Theme board

7.2.6 Usability team review

To assist in the selection of the best concept(s), the navigation and interaction concepts were reviewed by the available members of the usability team. The concepts that were reviewed are shown in Figures 40a & b and 41.

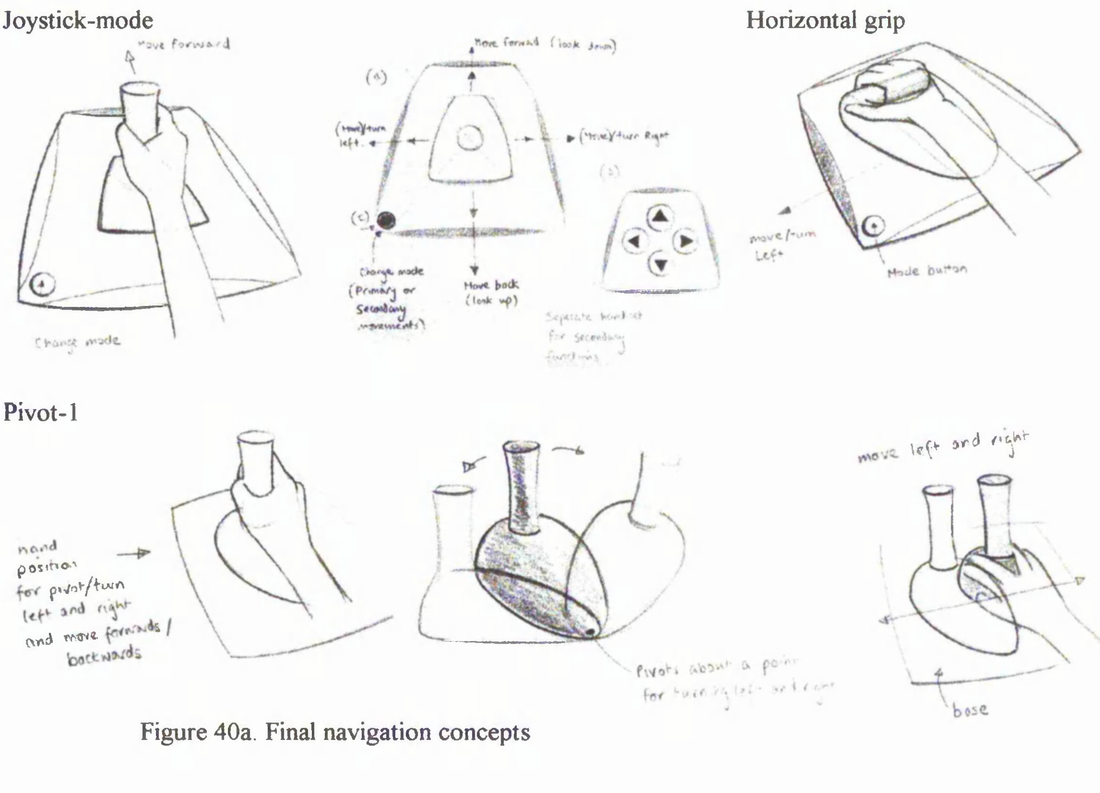


Figure 40a. Final navigation concepts

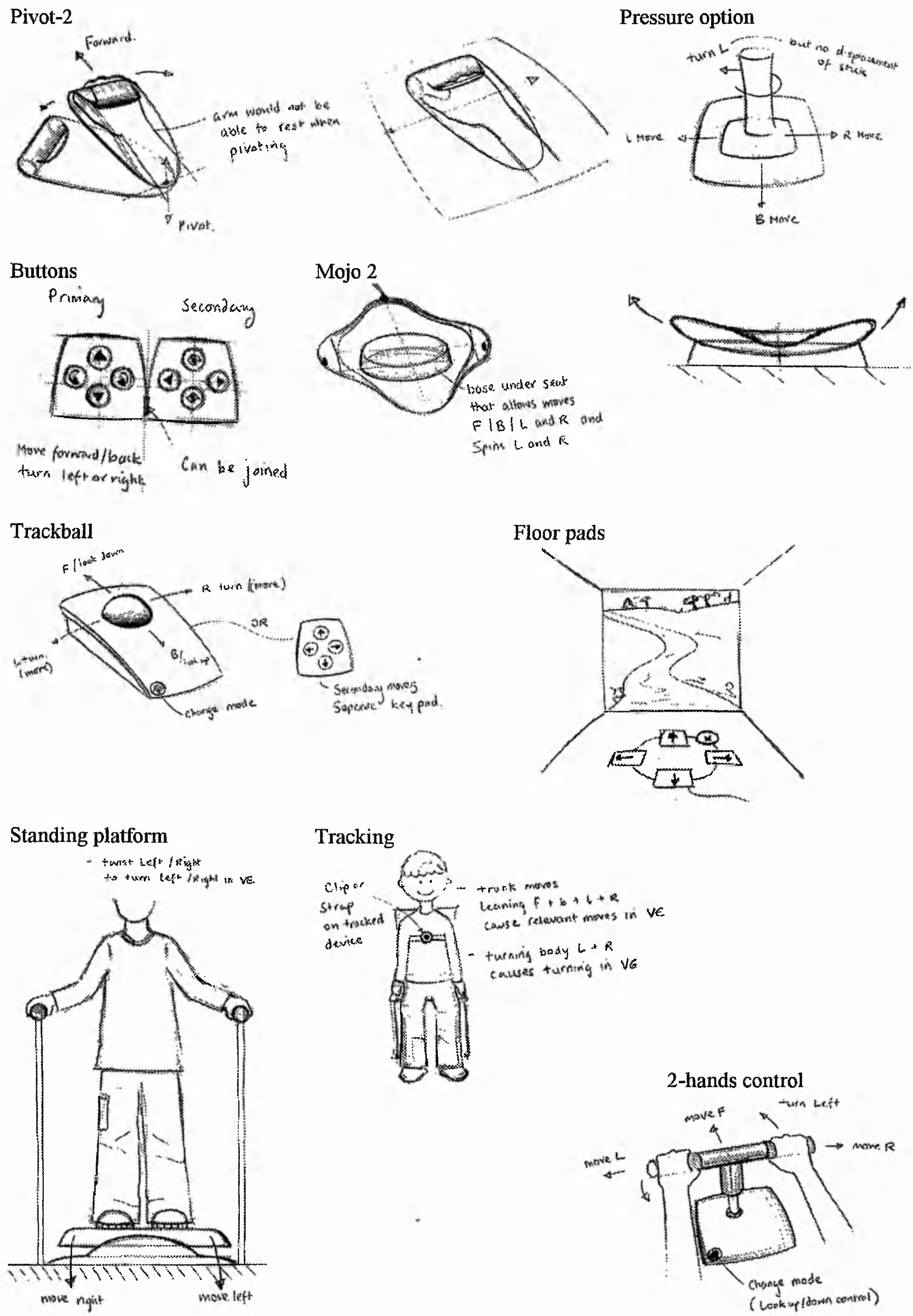


Figure 40b. Final navigation concepts

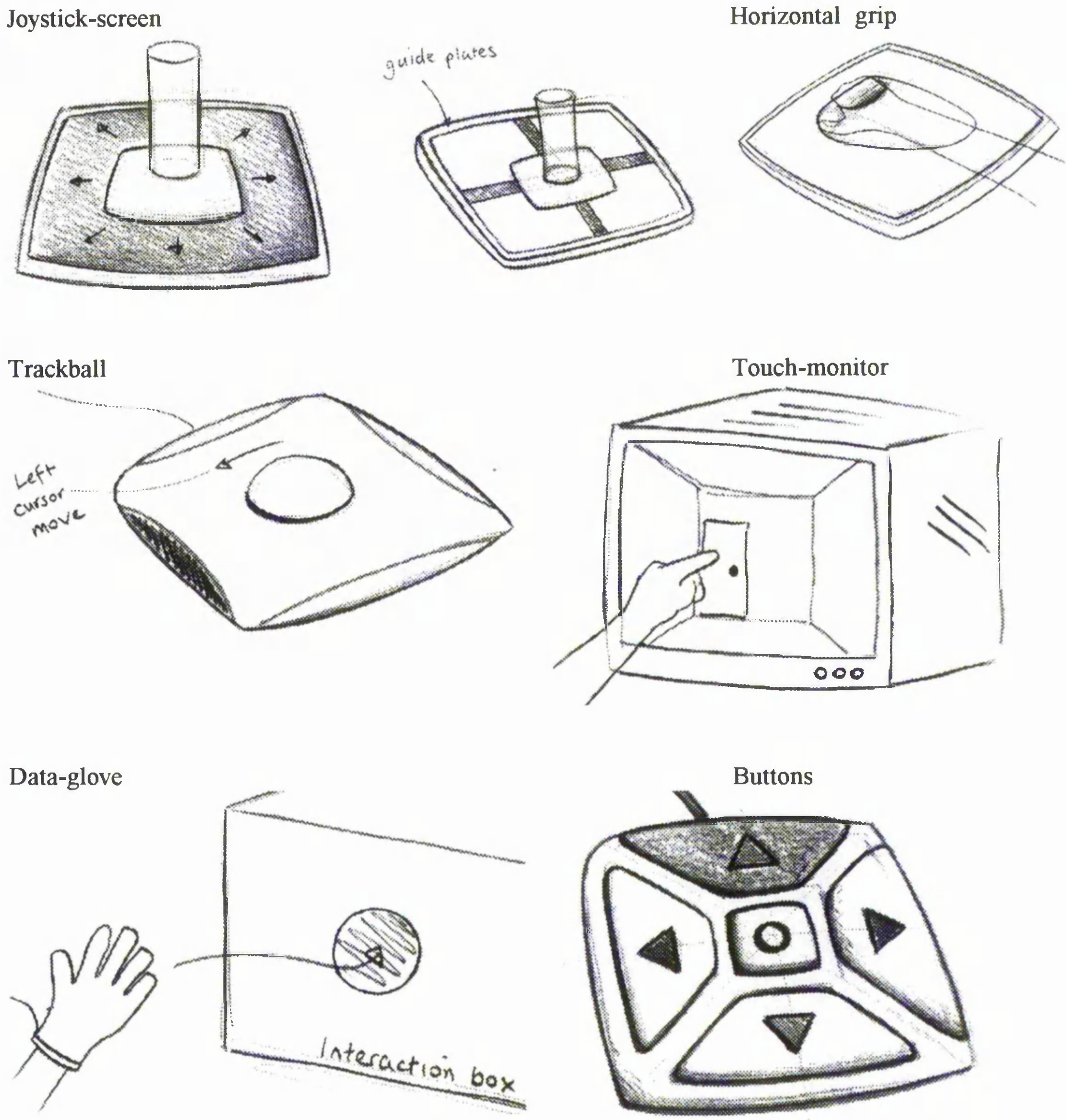


Figure 41. Final interaction concepts

The usability team feedback, on these concepts, is detailed in Appendix J. In brief, the type of feedback given concerned: predicted difficulties with the concepts; good features of the concepts; new ideas or features to try and recommendations to discontinue researching particular concepts. The new ideas that emerged from this review are depicted in Figure 42: tilting joystick and combined device.

Tilting-joystick | Combined interface

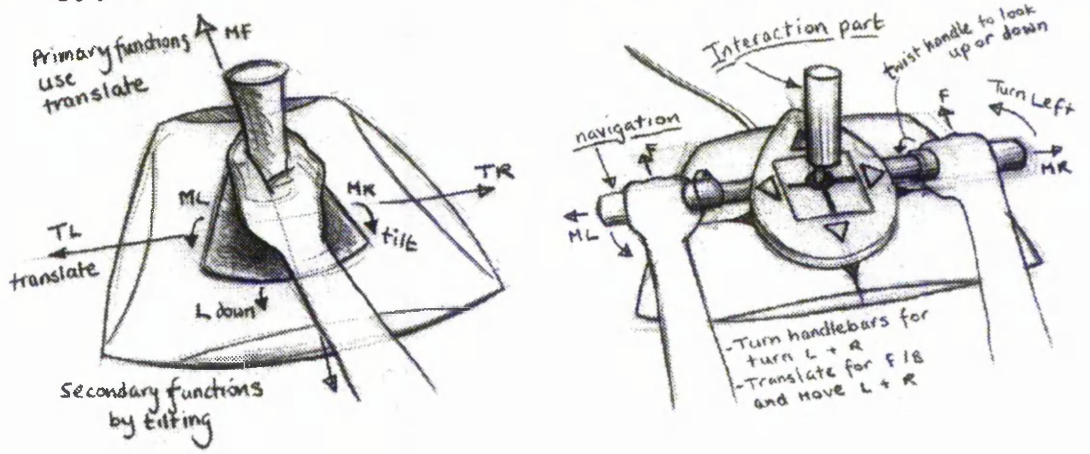


Figure 42. Developed concepts from usability team review

7.2.7 User group tests

Hand interface test

The hand interface test was conducted with 15 pupils from the VRD user group (see Chapter 5: 5.2 User group) to identify which type of interface they found easiest to grip. The choice was between the Ergo mouse, which requires a palmar grasp, and a prototype model, moulded so that the user's hand rests comfortably on it and no gripping is required. The Ergo mouse and prototype model are shown in Figure 43.

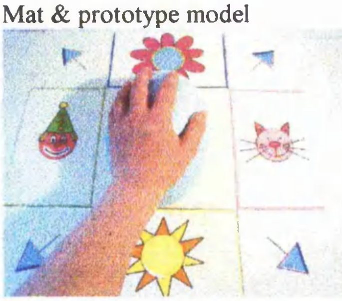
Task: the user was required to move each device in turn to an area on a prototype game mat (see figure 43). This enabled the tester to observe the user's control with the interface as each was moved in all directions.

Results: all 15 users tested were observed to have good control with the Ergo mouse using the palmar grasp. 11 users were observed to find the Ergo mouse easier than the prototype model and 4 were observed to control both interfaces with the same level of ease. Hence, it was concluded that the palmar grasp was the easiest interface for this user group.

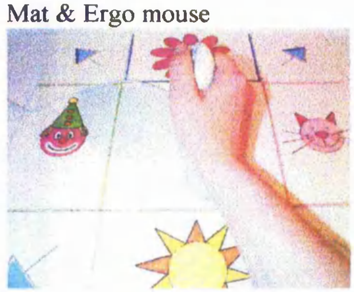
Ergo Mouse

Prototype model

Mat & prototype model



Mat & Ergo mouse



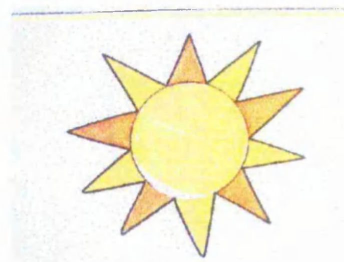


Figure 43. Images of hand interface test

Device test

5 pupils from the VRD user group (see Chapter 5: 5.2 User group) were observed using the Roller Joystick (Figure 44a), with guide plate attached, and the KidsBall (Figure 44b) to control an interaction task. This test was conducted to observe which device the users found easiest to control. The main characteristics of the 5 pupils were as follows: cognitive ability – 2 moderate/severe and 3 severe learning difficulties; physical ability – 4 gross and fine-motor difficulty, 1 just fine-motor difficulty and 4 also have a co-ordination difficulty.

a.

b.

Figure 44. a – Roller Joystick; b – KidsBall

Results: the observations from the device test are detailed in Table 30. This table shows that there were two difficulties with the roller ball: one user *moved it randomly* and one user *knocked it accidentally*. The observed problem with the joystick was *reduced speed of interaction*. The conclusions from this test were as follows:

- The most usable input device would need to be adaptable for different users, as some users found the roller ball easiest to use, whereas others found the joystick easiest to use.
- The guide plate must be optional, as this feature restricts the movement for some users

Table 30. Observations from device test

User	Observations
A	Roller ball: able to use fine Joystick: able to use fine; could progress to not need the guide plate
D	Roller ball: can use ok; knocked ball accidentally Joystick: more control with this device; could progress to not need the guide plate
E	Roller ball: moved randomly Joystick: controlled his movements; reduced random movement
G	Roller ball: able to use fine Joystick: able to use, but slower than roller ball; not need guide plate, restricts her movement
H	Roller ball: able to use fine Joystick: able to use, but slower than roller ball

7.2.8 Concept selection matrix

The concept selection matrix method (Baxter, 1995) is used to rank the final concepts against the selection criteria. The selection criteria, in this case, were the device attributes from the design specification. Two separate matrices were used, one for the navigation and one for the interaction concepts. Each concept is ranked 'better than' (+1), 'worse than' (-1) or 'same as' (0) a reference concept, which is the best current competitor to the proposed new product. For this project, the reference concepts were chosen to be the joystick for navigation and the mouse for interaction (not the best current competitors, but commonly used devices). The concept selection matrices and the selection criteria can be found in Appendix J. Table 31 details the results from the concept selection matrices. It is important to note that this method of concept selection would normally be carried out by team. Whereas, in this case, the selection matrices have only been completed by the author.

Table 31. Final concept list and results from selection matrices

Navigation	Total	Interaction	Total
Combined interface	21	Joystick	15
2-hands control	21	Joystick-screen	10
Joystick-mode	15	Horizontal grip	10
Pivot-1	15	Buttons	8
Tilting joystick	14	Trackball	6
Buttons interface	10	Touch-surface	6
Trackball	8	Touch monitor	3
Touch-surface	6	Data glove	0

Table 31 shows that the best navigation concept is either the 'combined interface' or the '2-hands control' and the best interaction concept was found to be the 'joystick'. The 'combined interface' is a combination of the '2-hands control' concept and the 'joystick' interaction concept. One of the design specification requirements is 'navigation and interaction functions in one device'. The benefits of this requirement are expected to be: *increased transparency* – as the user is not required to switch between devices; *increased focus on the VE* – as all functions will be centrally located on one device and compact design – *more integrated system*. Due to these benefits, and the results of the concept selection matrices, the decision was made to develop the 'combined interface' concept. Hence, this concept proceeded to the embodiment stage of the design process.

7.3 EMBODIMENT DESIGN

7.3.1 Technical analysis

Compatibility with VR software

The VEs that would be available for the user-based assessment of the new input device, were built using the Superscape VRT (Virtual Reality Toolkit). Hence the new device would need to be compatible with the Superscape Visualiser (used to run the VEs). The Superscape Visualiser will automatically recognise a selection of input devices. As the functions of the new input device, VR1, do not match any of the devices that Superscape already recognises, specific DLL and SCL code would need to be written and attached to the selected VEs (those that would be used to test the new device). Before proceeding with the development of this code, the Mojo prototype was examined.

Mojo - interactive seat for VE navigation

The Mojo prototype (pictured in Figure 6, Background) is a serial input device. DLL (Dynamic-Link Library) and SCL (Shape-edit Command Language) code, which reads inputs from the serial port, was written for this device. In order to avoid the time and cost involved in the development of additional code, an investigation was made to determine whether the serial DLL and SCL would also be suitable for VR1.

Unfortunately, the investigation led to obstacles. The designer had a hard copy of the DLL code, but was unable to obtain an electronic copy that could be loaded into a VE for testing the prototype. The next solution was to re-write the software, but the designer was unable to obtain the required Watcom C compiler software. If VR1 had been designed for serial port input, it would only be usable with the Ski VE, with which Mojo was tested. As the Ski VE would be limited to testing only left and right turn, this was not assessed as a suitable solution.

Solution: new DLL and SCL code was written specifically for VR1

Joystick

An analogue joystick was deconstructed to examine how it functioned. This revealed that, when the stick moves, it adjusts 2 potentiometers (POTs). The joystick returns to the centre when no force is applied. The returning force is achieved using a spring. Details on the standard PC joystick interface were obtained from the Internet. A diagram of this interface is shown in Figure 45 and the pinout is listed in Table 32.

As can be seen from Figure 45 and Table 32, 4 potentiometers can be connected to the joystick port. The navigation functions of VR1 required 4 axes of movement, 1 for forward/back move, left/right turn, left/right move and look up/down respectively (see Figure 46). As each axis of movement could be detected using 1 POT, it was decided that the navigation functions of VR1 would be interfaced with the joystick port.

Table 32. Pinout for PC joystick

Pin	Connection
1	XY1 (+5v)
2	Switch 1
3	X1
4	Ground (for switch 1)
5	Ground (for switch 2)
6	Y1
7	Switch 2
8	Not connected
9	XY2 (+5v)
10	Switch 3
11	X2
12	Ground (for switch 3 & 4)
13	Y2
14	Switch 4
15	Not connected

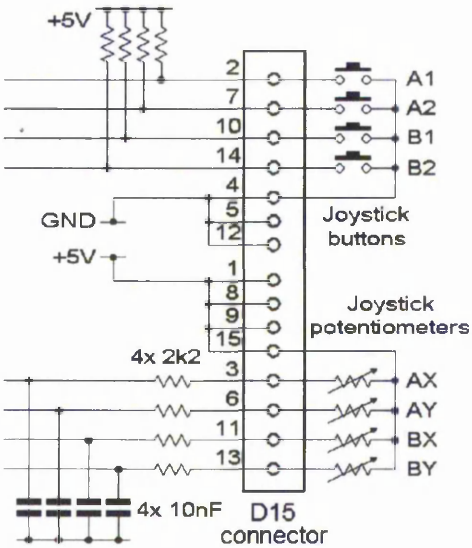


Figure 45. Standard PC joystick interface

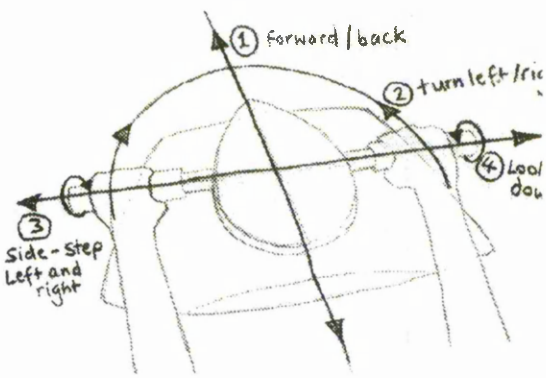


Figure 46. The 4 axes of movement of VR1

Figure 47. Strategic Commander

Strategic Commander

The Strategic Commander (SC) gaming device (Figure 47) was analysed for mechanical inspiration as it has similar functions to the navigation functions of VR1. The hand interface of the SC moves on a base and always returns to the centre when pressure is released. The hand interface can be moved forward/back, left/right, diagonally and twisted to cause left/right turn in the 3D game it is controlling. The main elements of mechanical inspiration for VR1 were obtained from the following: the plastic, lubricated guides that help to direct movement forward/back, left/right and diagonally and the sprung, rotary potentiometer, which enables the left/right turn function.

Roller joystick (Penny & Giles)

The Roller joystick (see figure 44a) is popular in some special needs schools as an alternative to the mouse. Penny & Giles kindly agreed to donate the joystick and circuitry, which was adapted for use as the interaction part of VR1. The decision was made to make use of this existing technology, to avoid reinventing the wheel!

7.3.2 Navigation prototype and VR1 driver

A prototype of the navigation functions was constructed, consisting of four 100 kΩ sliding potentiometers, 2 push buttons and the 15-pin joystick connector. This prototype was used to test the new DLL and SCL, which was written by Third Dimension Ltd. When the VR1 DLL and SCL were loaded into a VE, POT 1, 2, 3 and 4 would control forward/back move, left/right turn, left/right move and look up/down respectively. The threshold value and resulting speed of movement could be altered for each navigation function, by making a simple change to the SCL code. Increasing the threshold value of a function would make that function less sensitive to movement. Hence, a user would be required to move the function further for the VE to respond.

7.3.3 Technical design

Linear VR1 navigation functions

The linear VR1 navigation functions are forward/back and left/right (side step) movement (see Figure 48a). To ease mechanical design, sliding potentiometers have been used for the linear movements. Using sliding potentiometers, instead of rotary, avoided the need to design a mechanism that translates linear movement to rotational movement. The value of the sliding potentiometers is 100kΩ.

There are two main parts to the mechanical design of these functions: movement control and spring return. The movement control mechanism was inspired by the lubricated guides found in the Strategic Commander and the spring return mechanism was inspired by the analogue joystick. Table 33 lists the parts for these mechanisms and assembly drawings are detailed in figure 48 b & c.

Table 33. Parts for linear functions

Part	Name	Quantity
Movement control mechanism		
1	Cross-track	1
2	Guide	2
3	Square-stop	1
4	Bracket	4
Spring return mechanism		
5	Bracket track	8
6	Spring-pull	8
7	Slider	8
8	Spring	4
9	POT-move	2

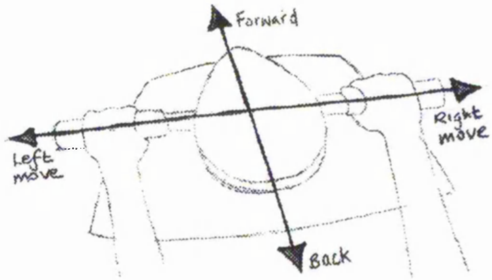


Figure 48a. Linear VR1 navigation functions

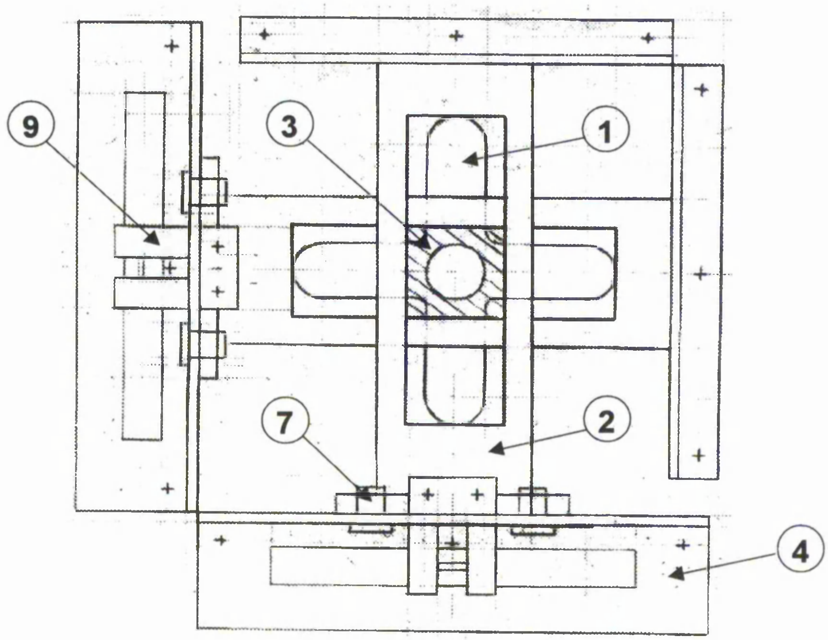


Figure 48b. Movement control mechanism

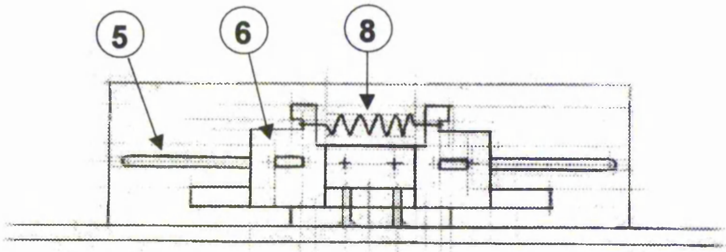


Figure 48c. Spring return mechanism

Rotational navigation functions

The rotational VR1 navigation functions are turn left/right and look up/down (see Figure 49a). Rotary potentiometers were used for these functions. Achieving turn left/right and look up/down only requires about 60 degrees of movement (not a full 360 degrees). Hence, a resistance range of about 100 kΩ was achieved using 470 kΩ potentiometers. 3 potentiometers were required: 1 for turn left/right, 1 for look up/down with the left handle and 1 for look up/down with the right handle.

The rotation mechanisms for both functions were inspired by the sprung rotary potentiometer in the Strategic Commander. Table 34 lists the parts for the rotation mechanisms and Figure 49 b & c show assembly drawings.

Table 34. Parts for rotational functions

Part	Name	Quantity
Turn left/right mechanism		
1	POT-bracket	1
2	POT-extension	1
3	Torsion spring	1
4	Spring-screw	2
5	Square-stop	1
Look up/down mechanism		
1	POT-bracket	2
2	Handle/POT-extension	2
3	POT-lock	2
4	Handle-support	2
5	Torsion spring	2
6	Spring-screw	4

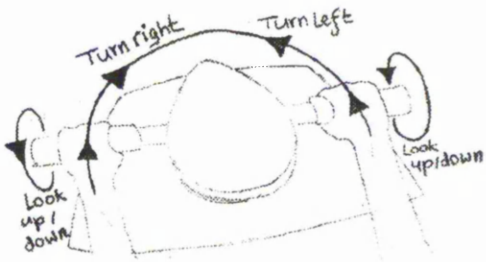


Figure 49a. Rotational VR1 navigation functions

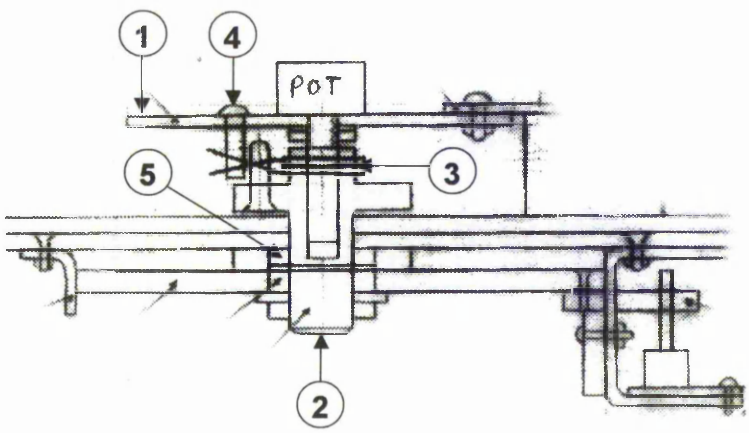


Figure 49b. Turn left/right mechanism

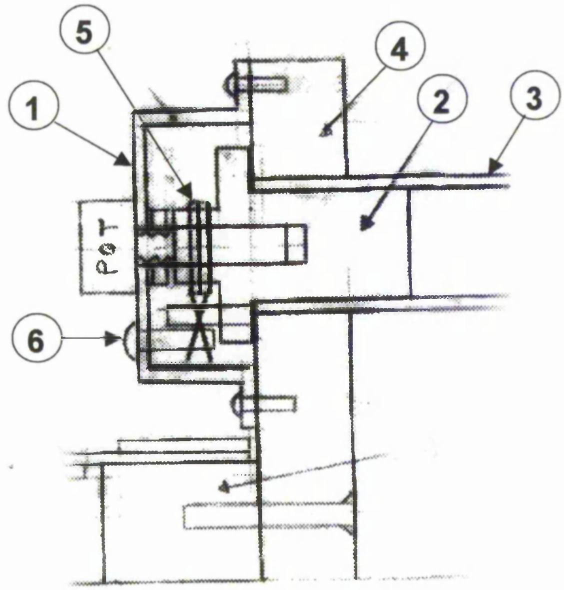


Figure 49c. Look up/down mechanism

Control box

The control box contains the circuit board for the navigation functions of VR1 (see Figure 50a). It also houses 3 toggle switches: 1 for turning side-step on/off, one for turning pitch on/off and one for selecting the left or right handle to be active for pitch control. Additionally, a push-button switch is fixed to the control box, which is required for configuring VR1 with the PC.

Interaction functions

As stated in the technical analysis section, the decision was made to use the joystick and circuitry of the Penny & Giles Roller joystick for the interaction part of VR1. The following changes and additions were made:

- The Roller joystick has a click and a double-click interaction switch. VE interaction for the user group only requires a single click (or left mouse button). For VR1, two switches (left and right) were connected for single click interaction.
- A push button on the Roller joystick allows 5 changes of cursor speed. This function was utilised on VR1, replacing the existing push button with a large silver push button (to fit with the modern styling of VR1).
- The user interface on the Roller joystick was replaced with a larger handle (see ergonomic design section).

Guide plate: the guide plate (Figure 50b) was engineered to meet the design requirements 'form indicates function' and 'provides necessary assistance'. Both requirements are met by the guide-slots, which show the user how to move and restrict user cursor control to vertical and horizontal movement. Attaching the guide-plate to VR1 is optional, as some users may not require the cognitive and physical assistance that it offers.

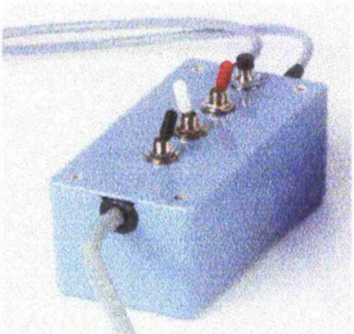


Figure 50a. Control box

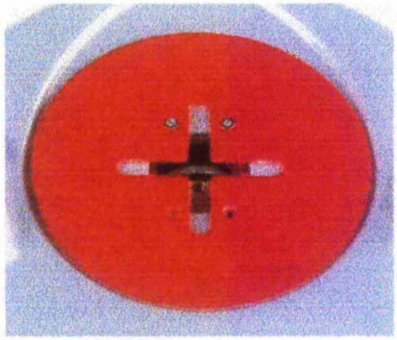


Figure 50b. Guide-plate

7.3.4 Ergonomic design

The anthropometric details for the ergonomic design of VR1 were obtained from Bodyspace (Pheasant, 1996).

Handles

The dimension details required for both the navigation and interaction handles were 'grip diameter' and 'length'. Bodyspace (Pheasant, 1996) recommends handle diameter to be between 30 and 45 mm and states that handle effectiveness increases with thickness. The user with the smallest handbreadth was able to grip the Ergo mouse (hand interface test), which had a grip diameter that ranges from 32-40 mm from bottom to top respectively. Hence, a grip diameter of 35 mm was chosen, for the handles on VR1, to ensure all users would be able to grip comfortably. The recommended handle length is 115-120 mm (Pheasant, 1996).

Solution: bicycle handle foam grips were found to satisfy both grip dimension requirements. They also meet a further design requirement of 'comfortable material for interface' (see Figure 51a).

Navigation handles: in additional to the details above, the dimensions for 'width apart' and 'clearance from VR1 base' were required. Bodyspace states that handles should be shoulder width apart or slightly less. The shoulder breadth dimensions for the user group were examined. The shoulder breadth range for 7-year-old girls to 19-year-old men is 245-430 mm. Hence, due to this vast range, it would probably be necessary to design a small and large version of VR1. However, as time only allowed the development of 1 prototype, a middle value of 300 mm was chosen, so that all users would be able to test the device. The clearance value was dependent on the users' finger width and range of movement necessary to achieve pitch. It was decided that a clearance value of 40 mm would accommodate these dependencies.

Interaction handles: for interaction, the angle of the handle was also important. The handle axis is required to be 100-110 degrees to the horizontal reference (plane on which forearm is resting) in order to keep the wrist in a neutral position and prevent strain. Hence, the interaction grip was designed to meet this ergonomic requirement (see Figure 51b).

Figure 51a. Foam grip

Figure 51b. Interaction handle

Muscle support

One of the requirements in the design specification is 'ergonomic design of muscle support'. However, VR1 has not been designed for the user to be able to rest his/her forearm on the device. The outer casings of the device have been shaped so that the user is able to grip and use the navigation or interaction functions without brushing the device with their forearm. Muscle support should be adequate, with the elbow resting on the work surface and the hand gripping the interface.

Moulding shape: for navigation, the sides of the base slope upwards (gradually) to the handle clearance height. For interaction, the shaping gradient is steeper to reach the height of the grip interface.

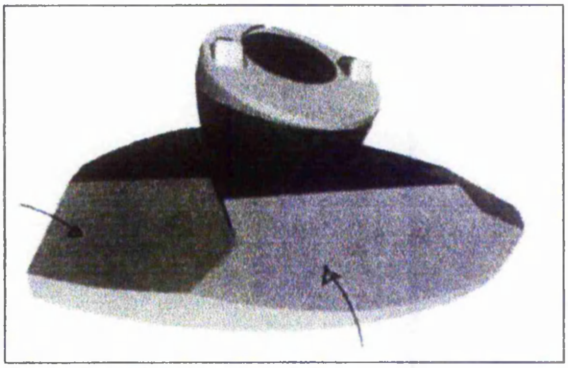


Figure 52. 3D software model

7.3.5 Casing design and assembled prototype

The casing of VR1 was designed to house the internal device parts, meet the ergonomic requirements and create the modern product style. 3D-design software was used to model the casing (see Figure 52). There are three parts to the prototype casing: 1 part for the base and two parts for the body. The body casing had to be designed in 2 parts to enable vacuum forming. Dimensioned drawings of the casing parts (see Appendix J) were given to a pattern maker to create the wooden patterns for vacuum forming. The 3D software was also used to experiment with the colour of the casing parts. The designer wanted one part of the casing to be a translucent coloured plastic and the other two parts to be a complementary opaque plastic. However, the vacuum forming trials, with the translucent plastic, were unsuccessful. The designer settled for silver-grey and purple plastic, which help meet the design requirement 'modern style, attractive colours'. The bottom part of the base was made from steel to meet the design requirement 'weighted base'. The assembled VR1 prototype is shown in Figure 53.

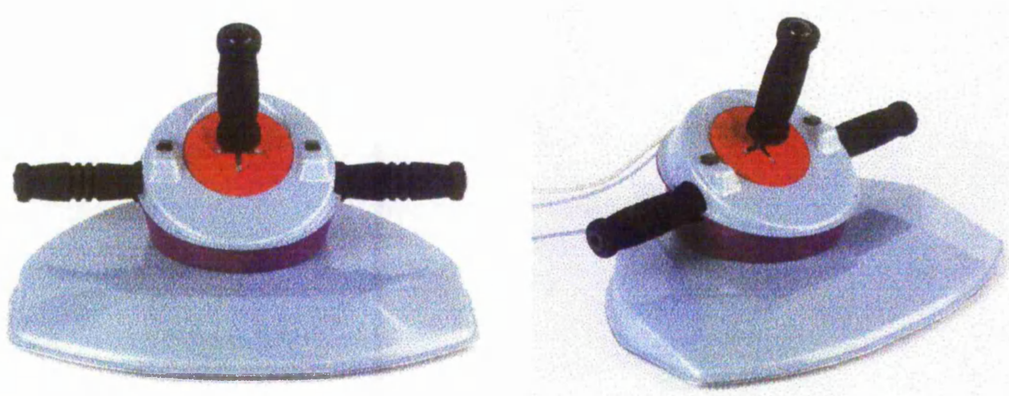


Figure 53. VR1 prototype

8. User-Based Assessment

8.1 INTRODUCTION AND OBJECTIVES

Following concept and prototype design, the next step of the multi-disciplinary design methodology was to conduct a user-based assessment of the developed VE input system. It was decided that the new computer input device, VR1, would be assessed against the JM system (Joystick and Mouse: commonly used by people with learning difficulties for VE navigation and interaction). This would determine the success of the employed multi-disciplinary design methodology.

The user-based observation for metrics method, which is outlined in the INUSE handbook of user-centred design (Daly-Jones, 1999), was utilised for this user-based assessment. This method entails a detailed analysis of users interacting with the particular systems being evaluated. The users' performance with both systems was noted by an observer and video recorded. The observations were then analysed in detail and appropriate usability metrics applied to assess usability. Reporting on this evaluation is based on the Common Industry Format (CIF) for Usability Test Reports (1999) and the Evaluation section of the ISO13407 European Standard (Human-centred design process for interactive systems).

Evaluation objectives:

- Evaluate the usability of VR1
- Compare the usability of VR1 and JM
- Identify whether VR1 meets the design requirements listed in the design specification
- Identify any usability difficulties with VR1 and suggest refinement

These objectives will allow the following hypothesis to be tested:

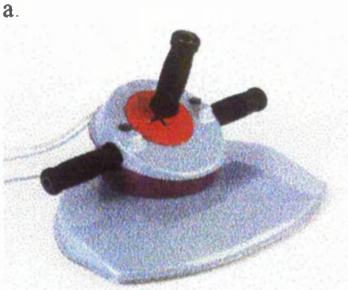
- The employment of the multi-disciplinary design methodology results in the design and development of a VE input system for young people with moderate to severe learning disabilities, which has greater usability than a commonly used system for this user population.

8.2 VE INPUT SYSTEMS EVALUATED

8.2.1 VR1 system

VR1 is the prototype that has been developed from the design specification (see Figure 54a). This prototype is used to control both navigation and interaction. VE navigation is controlled from the prototypes' handlebars (Figure 54b) and interaction is controlled from the cursor control handle and the interaction buttons (Figure 54c). With the guide plate attached, cursor control is restricted to vertical and horizontal movement. Interaction was tested with the guide plate on and off to evaluate its usability. Table 35 details the navigation and interaction functions of VR1.

a.



b.

c.

- a. VR1 prototype
- b. handlebars
- c. cursor control handle and interaction buttons

Figure 54. VR1 VE input system

Table 35. Navigation and interaction functions of VR1

Navigation functions
• Forward, backward, side-step left / right in VE – grip handlebars and push forward, backward, left and right respectively • Turn left / right in VE – grip handlebars and turn to left or right, as if riding a bike; • Look up / down in VE – grip active handlebar and twist up or down (like the accelerator of a motor bike)
Interaction functions
• Positioning the cursor (moving the cursor up, down, left and right) – grip the cursor control handle and move it up, down, left and right respectively • Interacting with the VE object – after positioning the cursor over the VE object, press the right or left interaction button

Alternative notation for VR1 functions (used in results tables, chapter 9):

- Handlebars = part-N or N
- Cursor control handle = part-I or I

8.2.2 JM system

The JM system consists of the joystick (J) for controlling navigation tasks and the mouse (M) for controlling interaction tasks. The Wingman joystick (Logitech) was chosen for this evaluation from the wide range of joysticks on the market. It was selected for its' robustness, simplicity (not too many excess functions) and quite suitable grip (size of grip suitable for most of user group). A two-button mouse was used for the interaction tasks. The Wingman joystick is shown in Figure 55 and the functions of the joystick and mouse are detailed in Table 36.

Figure 55. Wingman joystick (Logitech)

Table 36. Navigation and interaction functions of the JM system

Navigation functions (joystick)
• Forward, back, left and right turn in VE – grip the joystick and move forward, back, left and right respectively • Look up and down – grip the joystick, press the front joystick button and move the joystick back (look up) and forward (look down) • Side-step left and right – grip the joystick, press the top joystick button and move the joystick left and right
Interaction functions (mouse)
• Positioning the cursor (moving the cursor up, down, left and right) – grip the mouse and move forward, back, left and right respectively • Interacting with the VE object – after positioning the cursor over the VE object, press the left mouse button

8.2.3 Primary and secondary navigation functions

The navigation functions of both VE input systems have been categorised at either primary or secondary. The primary navigation functions are those that are most frequently used for achieving VE navigation tasks: move forward; move backward; turn left and turn right. Hence, the secondary navigation functions are: look up; look down; move left and move right.

Alternative description: the navigation function 'look up/down' has also been referred to as 'pitch' in the results tables (chapter 9).

8.3 EXPERIMENTAL DESIGN

Hypothesis

- The employment of the multi-disciplinary design methodology results in the design and development of a VE input system for young people with moderate to severe learning disabilities, which has greater usability than a commonly used system for this user population.

Variables

- Independent variable: multi-disciplinary design methodology
- Dependent variable: usability

Experimental conditions

- Experimental condition: the user group is observed using VR1 to control VE navigation and interaction tasks (VR1 – multi-disciplinary methodology employed in design)
- Control condition: the user group is observed using the JM system to control VE navigation and interaction tasks (JM – multi-disciplinary methodology NOT employed in design. *Note: the multi-disciplinary design methodology requires that you design for the specified users, tasks and environment. As no literature has been found to indicate that the joystick or mouse were designed for VE control for people with learning difficulties, it is justifiable to state that the multi-disciplinary design methodology was not employed in the design of the JM system.*)

8.4 METHOD

Test administrators

Two testers were present at the evaluations. The author's primary job was to guide the sessions, which involved briefing the user on the tasks, demonstrating how to use VR1, prompting the user when necessary and time taking. The author also noted observations of user performance.

A final year computing student, from the Nottingham Trent University had expressed interest in working with pupils with special needs and agreed to undertake the usability evaluation as part of her final year project. The nature of the evaluation fitted well with 'human-computer interaction', which is a major subject studied as part of the computing degree at Nottingham

Trent University. This tester took thorough notes during each evaluation session, with reference to the usability checklist and made sure the sessions were being video recorded correctly.

8.4.1 Participants

16 pupils, from the Shepherd School in Nottingham, were selected to form the UE (Usability Evaluation) user group. 13 of these pupils were in the VRD user group, which took part in the user analysis (see Chapter 5). Hence, the characteristics of these users are listed in the user analysis section of the context report (see Appendix F). The remaining 8 pupils from the VRD user group had left the school by the time of selection for the UE user group. As with previous user group selection, the 3 new pupils (X, Y and Z) were chosen based on the following criteria: cognitive ability to understand the VEs; not severely physically impaired (e.g. have some manual dexterity) and interested in working with computers. Table 37 details a selection of the user group attributes (the specific characteristics of 3 users [D, E and H] are detailed in Appendix F). The key characteristics of the user group are as follows:

- Gender: 10 male and 6 female
- Age range: 7 – 19
- Cognitive ability: the majority of the pupils have severe learning disabilities. A few of the users are bordering severe to moderate learning disabilities
- Physical ability: the pupils have moderate physical difficulties, including co-ordination, gross-motor and fine-motor difficulties. One pupil uses a wheelchair.

Table 37. UE user group attributes

User / gender	Age (at start of evaluation)	Cognitive difficulty	Physical difficulty	VE input systems tested	JM system previous use
Primary department					
X / Male	7:10	Mod / severe	C	VR1 / JM	J(m), M(m)
D / Male	8:10	Mod / severe	GM, FM, W	JM / VR1	J(f), M(m)
E / Male	9:11	Severe	GM, FM, C	VR1 / JM	J(f), M(f)
A / Female	9:11	Mod / severe	GM, FM, C	JM / VR1	J(m), M(f)
Secondary department					
C / Female	13:02	Severe	GM, FM, C	JM / VR1	absent
G / Female	14:05	Severe	GM, FM, C	VR1 / JM	J(m), M(f)
Y / Male	14:10	Mod / severe	FM, C	VR1 / JM	J(f), M(m)
Z / Male	15:05	Mod / severe	GM, C	JM / VR1	J(m), M(m)
16+ department					
M / Male	17:11	Severe	GM, FM	VR1 / JM	J(f), M(m)
H / Female	16:05	Severe	FM, C	VR1 / JM	J(m), M(f)
I / Female	17:02	Mod / severe	FM, C	VR1	J(m), M(f)
J / Male	16:07	Severe	C	VR1	J(f), M(m)
L / Male	16:10	Severe	GM, FM, C	VR1	J(m), M(m)
K / Male	16:09	Severe	FM, C	VR1 / JM	J(m), M(m)
N / Female	18:11	Mod / severe	FM	JM / VR1	J(f), M(m)
Q / Male	18:06	Mod / severe	GM, FM, C	JM / VR1	J(f), M(m)

Notes on table 35: in the 'cognitive difficulty' column, 'Mod / severe' means that the pupil borders the moderate to severe level of cognitive functioning. In the 'physical difficulty' column, GM = gross-motor difficulty, FM = fine-motor difficulty, C = co-ordination difficulty and W = has wheel chair. The column entitled 'VE input systems tested', also lists the order in which the systems were tested. The counterbalancing technique was used to eliminate any biased results, which could be attributed to order. As indicated in this column (VE input systems tested), 3 of the pupils (I, J and L) only tested VR1. Finally, in the 'JM system previous use' column, J = joystick, M = mouse, m = many and f = few. Hence, 'J(m), M(f)' means that the pupil has used the joystick many times before and the mouse a few times before.

UE (Usability Evaluation) introduction party

The test administrators held a party, with a virtual reality theme, to inform the user group about their involvement in the usability evaluation (see Figure 56). Each member of the user group received an invitation to the party.

Initially, everyone enjoyed a drink (cyber juice) and each member of the user group introduced themselves. Following this, a short presentation on the usability evaluation was given using overhead projector slides (see Appendix K). The pupils were told that they were all invited to be members of the UE user group and that this would require testing the VR1 input device and then sharing their opinion of the device with us. A short description of VR1 and the evaluation VEs was given to end the presentation. Finally, more cyber juice was enjoyed, along with cheese megabytes and other cosmic yummy delights.

Figure 56. UE introduction party

Certificate of appreciation: following the completion of the evaluation sessions, a certificate of appreciation (see Appendix K) was given to each member of the UE user group, in recognition of their contribution to the research.

8.4.2 Test facility and equipment

Test facility

Initially a small room, which contains the network server, was suggested for the evaluation. This room was suggested because it was the one where we were least likely to be disturbed in the school. However, this room was too small for the computer system, workstation and evaluation participants.

Figure 57. Test facility

An alternative schoolroom was chosen, which was rarely used at the time of the evaluation. The room was spacious, with several cubicles set up for working one-on-one with pupils. A cubical was selected in which to set up the evaluation equipment (see figure 57). The lighting and temperature in the room were appropriate and it was suitably quiet. Some disturbance occurred towards the end of the evaluation schedule, due to the organisation of the school's Christmas show. At this time, some staff members came in to the room with props and to sort out costumes. However, this caused very minimal distraction of the user group from the evaluation tasks.

Features or circumstances that could affect the results: the video camera was visible to the pupils and might have caused slight nervousness in some pupils. Others were not phased by the video recording at all, even asking to see themselves on the video after the session. Two testers were present during each evaluation, one guiding the session and one taking notes. The pupils were also aware that their sessions were being timed using a stopwatch. The tester observation and timing may also have increased pupil anxiety, perhaps affecting their performance.

Test equipment

The equipment that was used in the usability evaluation is detailed in Table 38. The computing environment is pictured in Figure 58.

Table 38. Test equipment

Computing environment
• Computer configuration: Pentium II School PC • Software: Superscape visualiser software to open the VEs; virtual factory and supermarket to evaluate the VE input systems • Display devices: screen size, resolution and colour setting • Audio device: two speakers were used • Workstation: classroom desk and chair
Test administrator tools
• Hardware: Video camera and tapes, note recording equipment, stopwatch, digital camera • Usability checklist • Questionnaires: Q1 - usability of VR1, Q2 - comparison of usability of VR1 and JM

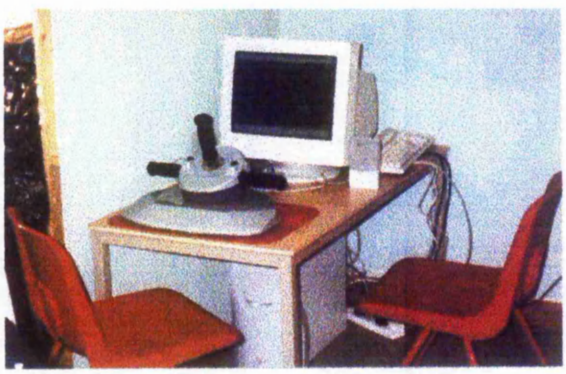


Figure 58. Computing environment

8.4.3 Tasks

From the virtual environments (VEs) that have been developed for people with learning difficulties, the virtual factory and supermarket, developed by VIRART, were selected for this evaluation. These VEs were chosen as they provide sufficient tasks for the evaluation of navigation and interaction. The factory VE was used for the majority of the evaluation sessions and the supermarket VE was only used near the end of the evaluation to test the users' control of the VR1 pitch function. The virtual factory and supermarket tasks are detailed in Tables 39 and 40.

Table 39. Virtual factory tasks

Task	Test
Initial test	Obviousness of system
Enter building	Navigation (into building)
Put on protective clothes	Navigation (to cupboard); interaction (with cupboard and clothes)
Enter factory	Navigation (into factory)
Report oil	Navigation (to oil); interaction (with VE man and oil)
Report ladder	Navigation (to ladder); interaction (with VE man and ladder)
Report trolley load	Navigation (to trolley); interaction (with VE man and trolley load)
Report first aid kit	Navigation (to first aid); interaction (with VE man and boxes)
Go up stairs	Navigation (up stairs)
Put containers away	Navigation (to cupboards); interaction (containers and cupboards)
Go down stairs and out of factory	Navigation (down stairs and out of factory)

Table 40. Virtual supermarket tasks

Task	Test
Enter supermarket	Navigation (into supermarket)
Select 2 pineapples	N (to pineapples); I (select pineapples); N (check trolley)
Select 1 orange	N (to oranges); I (select orange); N (check trolley)
Select 1 tomato	N (to tomatoes); I (select tomato); N (check trolley)
Select 2 milk cartons	N (to milk; I (select milk); N (check trolley)
Select 2 packets of cereal	N (to cereal); I (select cereal); N (check trolley)
Select 1 tea bags or coffee	N (to tea/coffee); I (select tea/coffee); N (check trolley)
Select 1 ice-cream	N (to ice-cream); I (select ice-cream); N (check trolley)
Go to checkout	Navigation (to checkout)
Put goods onto belt	Interaction (double click on each item)

8.4.4 Session procedure

The 16 pupils in the UE user group all tested VR1. 13 of these pupils tested the JM system. As previously stated, counterbalancing was used to eliminate any biased results, which could be attributed to order. The order in which the systems were presented to the users is shown in Table 37, column 5 (VE input systems tested). Each pupil used VR1 3 times with the virtual factory and 9 pupils used VR1 once with the virtual supermarket to further test the pitch function. The interaction guide plate was removed for each pupils' third session with VR1. The 13 pupils who used JM, only used this system once (with the virtual factory), as they all had previous experience with the joystick and mouse (see Table 37, column 6).

Session time: for each session, the users were given a maximum of 15 minutes to complete the tasks. The users' time to finish the tasks was recorded for each session.

Initial test: before giving a demonstration of the functions of VR1, the initial test was conducted. This test involved asking each user to 'have a go' with VR1, with no prior instruction. This test was conducted to assess VR1 for the usability attribute 'obviousness'. As previously stated, all of the users had previous experience with the joystick and mouse, hence, the initial test could not be conducted with the JM system.

Demonstration: a demonstration of how to achieve navigation and interaction control, with both systems, was only given if the user required it. If a user showed competency with a function without demonstration, it was felt unnecessary to demonstrate that particular function. Due to the cognitive ability and diverse range of communicative ability of the UE (Usability Evaluation) user group, it was difficult to adhere to a standard procedure in terms of instruction and direction given to the subjects.

Greeting and dismissing: the user was welcomed by both test administrators, told which system they were going to use and asked their permission to video the session. All pupils agreed to the sessions being video taped. At the end of each session the user was thanked for his/her participation and encouraged about his/her performance.

8.4.5 Usability metrics

The usability team (see Chapter 4: 4.4.2 Multi-disciplinary design methodology) agreed on the methods, described in this section, for evaluating the usability of VR1 and comparing the usability of VR1 and the JM system.

The usability engineering process, outlined by Faulkner (1998), was employed to define a set of usability metrics for evaluating the VE input systems. The HCI process requires that you first produce a usability specification, which is a statement of the usability attributes that will be examined. For this evaluation, the 'guiding principles' for the requirements of non-keyboard input devices (found in section 4 of the ISO 9241-9 European Standard) have been selected for the usability attributes. These 'guiding principles' (usability attributes) are as follows: obviousness; predictability; consistency; compatibility; efficiency; effectiveness; feedback; satisfaction; controllability and biomechanical load. Table 41 lists the definitions of these usability attributes (taken from ISO 9241-9).

Usability Specification

The usability specification (Table 42) states the usability attributes, how these usability attributes will be measured (the metrics) and any pre-conditions for measurement. One or more metrics were specified for each usability attribute. For example, the usability factor 'obviousness' was measured using the following metrics: initial test; training (instruction required) and learning time.

Table 41. Definitions of the usability attributes

Operability
• Obviousness: intended use obvious or easily discovered • Predictability: operates and responds according to user expectations • Consistency: always operates and responds in same manner • Compatibility: accommodates anthropometric characteristics and biomechanical capabilities of user population • Efficiency: functions with least amount of time and effort • Effectiveness: design leads to enhanced or optimised user performance by means of accuracy and completeness • Feedback: effective feedback: perceptible and understandable indication that device reacting to user actuation • Satisfaction: leads to freedom from discomfort and enhances positive attitudes of users towards its use
Controllability
• Responsiveness: feedback is consistent and accurate • Non-interference: does not interfere with own use • Grip surface: grip and contact surface prevents unintended slipping during use • Device access: can be grasped, positioned and manipulated quickly and easily • Control access: controls can be located and actuated quickly and easily
Biomechanical load
• Postures: can be operated without undue deviation from neutral posture • Effort: operated without excessive effort • User training: when informed of proper use, and make use of such information, can avoid excessive effort and obtain improved performance

Table 42. Usability Specification

Attribute	Metric	Pre-conditions
Obviousness	Initial test	No prior use
Obviousness	Training	
Obviousness	Learning time	No prior use
Predictability	User comments / reactions	
Predictability	Can use after training	After adequate training
Predictability	Harshness	After adequate training
Compatibility	Anthropometric difficulties	
Compatibility	Biomechanical difficulties	Last session counts
Efficiency	Task time	Best time counts
Efficiency	Harshness	Last session counts
Effectiveness	Unproductive actions – device	After learning period
Effectiveness	Unproductive actions – task	After learning period
Effectiveness	Disorientation	After learning period
Effectiveness	Support – verbal	Last session most sig.
Effectiveness	Support – physical	Last session most sig.
Effectiveness	Task completion	After learning period
Satisfaction	Comfort	
Satisfaction	User attitude	
Controllability	Responsiveness	
Controllability	Non-interference	
Controllability	Grip surface	
Controllability	Device access – positioned easily	
Controllability	Device access – grasped easily	
Controllability	Device access – manipulate easily	
Controllability	Control access – located easily	
Controllability	Control access – actuated easily	
Biomechanical load	Neutral posture deviation	
Biomechanical load	Effort	Last sessions most significant
Engagement	Distraction	

Usability checklist: this checklist was used to record the relevant data from the notes taken and video analysis of the evaluation sessions. Examples of completed usability checklists can be found in Appendix L.

Attributes omitted from usability specification: the usability attributes 'consistency' and 'feedback' were omitted from the usability specification as they are integral to the devices and hence, the author expected that both VE input systems would satisfy these usability requirements. However, these factors were monitored during the evaluation for any unpredicted difficulties.

Attributes added to usability specification: 'engagement' was added to the usability specification and measured by the level of distraction observed during the evaluation sessions.

Extended usability specification

The extended usability specification is used to set planned levels for the usability attributes, enabling the application to be measured against a scale (Faulkner, 1998). This specification states the 'worst case', 'lowest acceptable level', 'planned case', 'best case' and 'now level' for each measure. Table 43 details the definitions of these planned levels of usability.

Table 43. Definitions of planned levels of usability

- Worst case – worst possible scenario for the system and one that will make it unacceptable
- Lowest acceptable level – the lowest level of performance that is acceptable by the user
- Planned case – the level that the system is expected to achieve
- Best case – the best possible scenario
- Now level – the current state of the system

For this particular evaluation, the 'now level' was taken to be the users' performance with the JM system, as the joystick and mouse are commonly used by people with learning difficulties for VE control. As the 'planned case' is the level that the system was expected to achieve, this level of performance was taken to be 100%. Anything less than the 'planned case' will be less than 100% performance on that measure and anything greater than the 'planned case' will be better than 100% performance. Completed examples of the extended usability specification are shown in Appendix L.

The performance measurement table

The performance measurement table (PM-table) was devised so that a statistical analysis could be performed on the resulting evaluation data, in order to compare the usability of the two VE input systems. The PM-table is actually the extended usability specification with a rating scale applied to each metric. For example, the metric 'initial test' has the following rating scale: 1 = can't use; 2 = use 1 function; 3 = use some functions; 4 = can use; 5 = can use well. The employment of this type of rating scale is described by the Wilcoxon matched pairs signed-ranks test (Greene and d'Oliveira, 1990), which was the chosen statistical analysis test for this study. A rating scale was not appropriate for the controllability metrics. In this case, 1 point was awarded if the metric was satisfied. Hence, as there were 8 measures of controllability, there were 8 points available. Completed examples of the PM-table are shown in Appendix L.

8.5 CONFIGURATION

Virtual supermarket

When the virtual supermarket was used, it was necessary to change the wiring of the VR1 potentiometers so that the device responded correctly to user movement. If the wiring was kept the same as for the virtual factory, the VE would move backwards with user forward movement of the device and forwards with user backwards movement of the device. This configuration problem was due to the software structure of the virtual supermarket and not to VR1.

VR1 Control box

The control box houses 3 toggle switches: 1 for turning side-step on/off, one for turning pitch on/off and one for selecting the left or right handle to be active for pitch control. However, it was discovered that the PC system could only read the device when side-step and pitch where switched on. In order to turn side-step or look up/down off, a very large 'dead zone' (threshold) had to be set up for these functions.

VR1 dead zone and speed

As previously stated, the dead zone (threshold) and resulting speed of movement could be altered for each navigation function, by making a simple change to the SCL code. Increasing the dead zone of a function would make that function less sensitive to movement. Hence, a user would be required to move the function further for the VE to respond.

Several versions of the virtual factory were set up with different dead zones and speeds for VR1 navigation. A selection of these versions is listed in Table 44.

Table 44. Virtual factory configurations

Factory	Dead Zone	Speed
A	Small	Quick
B	Small	Slow
C	Large	Slow
D	Large	Quick
E	Medium	Quick
F	Medium	Medium

The author tested VR1 with the created versions of the virtual factory to identify the one that was easiest to control, which was factory-F. A further virtual factory was required, which eliminated the secondary navigation functions of side-step and pitch. This was done by saving a version of the virtual factory (I) with very large dead zones for both pitch and side-step. Factory-F was used by 4 pupils for their first evaluation session with VR1. From these initial evaluation sessions it was observed that the pitch function was interfering too much when using factory-F. Hence, factory-J was created, which was the same as factory-F, but with a larger dead zone for pitch (to help decrease interference). Thereafter, the pupils were initially observed using VR1 with factory-J, and if the pitch function was still interfering with use, factory-I would be used, until the pupils showed competency with the primary navigation functions.

Joystick configuration

The joystick settings were adjusted in the proportional control set-up of the Superscape visualiser to stop the VE from randomly spinning when the joystick was connected. The spinning occurred because the dead zones were too small. The speed was reduced and the dead zone increased to make the joystick easier to control for the user group.

VR1 prototype adjustment

On the first day of the usability evaluation part of the VR1 prototype broke. This occurred when a user turned the handlebars too far to the right and consequently one of the plastic guides in the base snapped. JB Engineering Ltd. was asked to produce two more guides from nylon, which is a stronger and less brittle plastic. The dimensions of the guides were also increased, as much as possible, to further increase their strength.

9. User-based assessment – results, discussion and conclusions

9.1 INTRODUCTION

This chapter reports on the results of the user-based assessment. There are two main result sections: the usability analysis of VR1 and the comparison of the usability of VR1 and JM system. The first section (usability analysis of VR1) will cover the overall usability of VR1, the obviousness (usability attribute) of VR1 and questionnaire 1 (Q1), which was used to obtain the users' opinion of the usability of VR1. The second section (comparison of the usability of VR1 and JM) will present a comparison of the overall usability of both systems and the results for the following usability attributes: compatibility; efficiency; effectiveness; satisfaction; biomechanical load and controllability. Additionally this section will include the results from questionnaire 2 (Q2), which was designed to obtain the users' opinion of the most usable system. Before presenting the results, the following will be discussed: changes to usability metrics; statistical analysis details; the conclusion tables and the calculation methods employed to obtain the results.

Changes to usability metrics

Once all the evaluation data had been added to the usability checklist under the correct measure, it was evident that limited data had been observed for some of the measures of the usability attribute predictability. No data had been noted for 'user comments / reactions' or for 'harshness', only for 'use after training'. As 'use after training' is also a measure of system effectiveness, this measure was moved to the usability attribute effectiveness, and predictability was removed from the data analysis. A further change was made, which effected both biomechanical load and efficiency. The measures of efficiency before this change were 'task time' and 'harshness'. As an efficient system is one that functions with the least amount of time and effort, it was decided that 'effort' should be moved from biomechanical load to efficiency to strengthen the measurement of this attribute.

9.1.1 Statistical analysis

Chosen test

The Wilcoxon matched pairs signed-ranks test was selected for the statistical analysis of the results of the usability evaluation. This test is appropriate for a two-condition related design when the same or matched subjects perform under both conditions. The test was applied using the computer package StatView 4.0 from Abacus Concepts, Inc.

Data analysed

The data observed in the usability evaluation was transferred from the usability checklist to the performance measurement table (see Appendix L). A total usability score was calculated for each user for both systems. This was done by adding the ratings of the user's performance for each usability metric. A statistical analysis was performed on these usability scores to identify the significance of these results.

A statistical analysis was also performed on the results for the attributes of usability. For this, only the ratings of the measures relevant to the particular attribute were totalled. The analysis was then conducted on the scores for each usability attribute.

Omitted users and usability factors

As shown in Table 37, chapter 8, 3 of the pupils (I, J and L) from the user group only tested the VR1 input system. The statistical analysis is based on the results of the 13 subjects that used both systems. However the results for these 3 users (obtained using JM system data from the Input Device Evaluation, chapter 3) have been included on the charts, for interest purposes only.

The usability attribute obviousness has not been included in the statistical analysis of usability. The reason for this is that only VR1 was assessed for this attribute. JM could not be assessed for obviousness during the usability evaluation as all users had previous experience with the joystick and mouse (see Table 37, chapter 8). The usability attribute engagement has been omitted from the statistical analysis as it gives a reflection of the usability of the whole VE system, including the software and environment, rather than just the input device(s).

Results

The results obtained from the Wilcoxon signed rank test, using StatView 4.0, are detailed in the relevant section of the results of the usability evaluation.

9.1.2 Planned (100%) usability

Table 45. Planned usability

Measure	Planned case	Rating
Planned (100%) obviousness = 9		
Initial test	Use some functions	3
Training	Demo	3
Learning time	3 sessions	3
Planned (100%) compatibility = 8		
Anthropometric difficulties	None	4
Biomechanical difficulties	None	4
Planned (100%) efficiency = 9		
Task time	OK / average	3
Harshness	Minimal	3
Effort	No effort	3
Planned (100%) effectiveness = 26		
Unproductive actions - device	None	4
Unproductive actions – task	None	4
Disorientation	None	4
Support verbal	Minimal	3
Support physical	None	4
Task completion	100%	4
Use after training	Can use (most)	3
Planned (100%) satisfaction = 4		
Comfort	Comfortable	2
Content state	Content	2
Planned (100%) biomechanical load = 2		
Neutral posture deviation	Non-harmful deviation	2
Planned (100%) engagement = 4		
Distraction	No distraction	4
Planned (100%) controllability = 8		
Feedback consistent/accurate	Yes	1
Interferes with own use	No	1
Prevents unintended slipping	Yes	1
Positioned easily	Yes	1
Grasped easily	Yes	1
Manipulated easily	Yes	1
Control access – located easily	Yes	1
Control access – actuated easily	Yes	1
Planned (100%) usability 1 (excluding engagement)		**66**
Planned (100%) usability 2 (excluding engagement + obviousness)		**57**

As stated in the usability metrics section (*previous chapter*), the extended usability specification lists the 'planned case', 'best case', 'lowest acceptable case' and 'worst case' for usability. The 'planned case' is the level that the system was expected to achieve and therefore this level of performance was taken to be 100%. As the PM table gives a rating value for each planned case, a planned usability value could be calculated. This planned usability value, which is 100% usability, was calculated by adding the rating values of the planned case for each measure. A planned total for each usability attribute was also calculated, by adding the rating values of the planned results relevant to each attribute. Table 45 lists the planned cases for each measure, the rating values, the planned usability value and the planned attribute values.

There are two 100 % usability values given in Table 45. Planned usability 1, which includes obviousness, could not be used to compare the usability of both VE input systems. As previously stated, the JM system could not be assessed for obviousness during the usability evaluation as all users had previous experience with the joystick and mouse. Hence, planned usability 1 could only be used to comment on the usability of VR1. As with the statistical analysis, the usability factor engagement has been omitted from both totals as it gives a reflection of the usability of the whole VE system, including the software and environment, rather than just the input device(s).

Percentage of planned usability and planned usability attributes

Each user's performance, with the VE input systems, was analysed by calculating a percentage of planned usability (% PU) and a percentage of the planned usability attributes (% P-UA). The first usability assessment was applied just to VR1. This analysis of usability included the usability attribute 'obviousness'. In order to calculate the % PU for each user, the rating values of the performance recorded for each measure were totalled, excluding engagement. Planned usability 1 (66), from Table 45, was then used to complete the calculation. The following is an example of this calculation:

User X:
Total of rating values for VR1 (excluding engagement) = 64
100 % usability (planned usability 1) = 66
% PU for VR1 = $(100 \div 66) \times 64 = 97$ %

When comparing the usability of both VE input systems, planned usability 2 (57), from Table 45, was used to calculate the % PU. In this case, the first step involved totalling the rating values of the performance recorded for each measure, excluding engagement and obviousness.

An example calculation follows:

User X:
Total of rating values for JM = 49
100 % usability (planned usability 2) = 57
% PU for JM = $(100 \div 57) \times 49 = 86$ %

Total of rating values for VR1 = 55
% PU for VR1 = $(100 \div 57) \times 55 = 96.5$ %

The percentage difference between the % PU of the two systems was also calculated for each user, for example:

User X:

% difference in % PU = 96.5 – 86 = 10.5 %

The % P-UA (percentage of planned usability attribute) values were calculated using the planned attribute values, which are listed in Table 45, e.g. planned controllability equals 8. In this case, the rating values of the performance recorded for each user were totalled for each usability attribute. The following is an example calculation for controllability:

User X:

Total of rating values for controllability for JM = 6

100 % (planned) controllability = 8

% P-controllability for JM = $(100 \div 8) \times 6 = 75$ %

Total controllability for VR1 = 8

% P-controllability for VR1 = 100 %

For all usability attributes, except obviousness, the percentage difference was also calculated:

User X:

% difference in % P-controllability = 100 – 75 = 25 %

9.1.3 Conclusion tables

As stated in the previous chapter, the objectives of the user-based assessment were as follows:

- Evaluate the usability of VR1
- Compare the usability of VR1 and JM
- Identify whether VR1 meets the design requirements listed in the design specification
- Identify any usability difficulties with VR1 and suggest refinement

At the end of the result section for each usability attribute (except biomechanical load), there will be a conclusion table. These tables will cover the last 2 objectives, as they will list the following:

- The device attributes 'met' and 'NOT met' by VR1, which are relevant to the particular usability attribute
- The usability difficulties identified with both VE input systems
- Suggested refinement to improve the overall usability of VR1

It is important to note that the device attributes 'met' and 'NOT met' will not be listed in the conclusion tables for efficiency and effectiveness. The reason for this is that all of the device attributes, from the design specification, could be attributed to the one of the other usability attributes.

9.1.4 Chart selection & notation in result tables

A line chart has been selected to display the % of planned usability and the usability attributes. The purpose of the line is to depict the trend of the results to the reader.

Notation has been utilised in the result tables when describing the VE input systems:

- For VR1: handlebars = part-N or N; cursor control handle = part-I or I
- For JM: joystick = J; mouse = M

9.2 USABILITY ANALYSIS OF VR1

9.2.1 Overall usability

Results

The % PU for VR1 was calculated for each user and these percentages are depicted on Chart 1. A summary of the results is listed in Table 46.

Table 46. Summary of usability of VR1 (including obviousness)

No. of users	% usability	Description
3	81 – 90	Between 10 and 19 % less than planned usability
6	93 – 99	Between 1 and 7 % less than planned usability
1	100	Same as planned usability
6	101 – 111	Between 1 and 11 % greater than planned usability

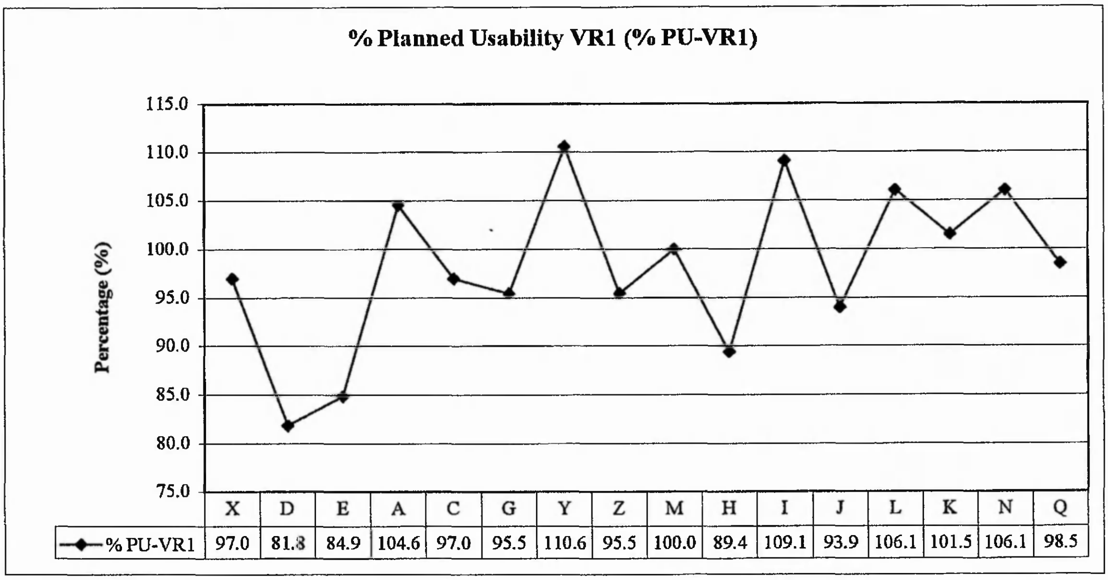


Chart 1. % of planned usability for VR1

Discussion

As can be seen in Table 46 and Chart 1, there are no drastically low results for VR1 usability. A good result was recorded by the user who equalled planned usability and by the 6 users who scored better than planned usability. For the 9 pupils who scored less than 100% usability, there is room for improvement in the usability of VR1. In order to identify how usability could be improved, it is necessary to examine the individual attributes of usability. All of the usability attributes will be analysed in a later section that compares the usability of VR1 with JM. As the JM system was not measured for obviousness, this usability attribute will be analysed in this present section.

Conclusion

VR1 was found to be equal to or greater than planned usability for 7 pupils, which, in the author's opinion, is a very good result. However, as 9 pupils scored less than 100% usability, future research is required to improve the usability of VR1.

9.2.2 Obviousness

Results

The percentage of planned obviousness (% P-obviousness) results for VR1 are depicted on Chart 2 and a summary of the results is listed in Table 47.

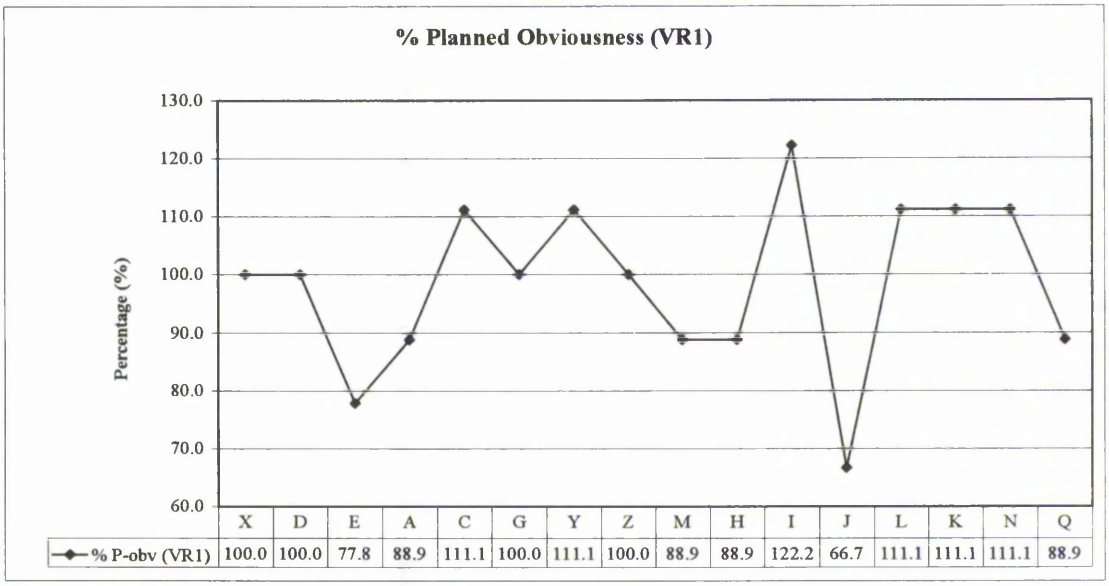


Chart 2. % of planned obviousness for VR1

Table 47. Summary of obviousness results

No. of users	% obviousness	Description
1	66.7	33.3 % less than planned obviousness
1	77.8	22.2 % less than planned obviousness
4	88.9	11.1 % less than planned obviousness
4	100	Same as planned obviousness
5	111.1	11.1 % greater than planned obviousness
1	122.2	22.2 % greater than planned obviousness

Chart 2 and Table 47 show that there are 2 users with unsatisfactory obviousness results: 66.7 % and 77.8%. The remaining 14 users found VR1 to be quite obvious, 4 of which equalled planned obviousness and 6 with exceptional scores greater than planned obviousness. Table 48 details a selection of the obviousness results.

Table 48. Selection of the obviousness results

User	% obviousness	Comments
J	66.7	Use 1 function; some further instruction; 4 sessions - - -
E	77.8	Use 1 function; some further instruction - -
A	88.9	Some further instruction -
M	88.9	Some further instruction -
Y	111.1	Can use +
L	111.1	2 sessions +
N	111.1	2 sessions +
I	122.2	1 session + +

Discussion

Obviousness difficulties

Table 48 shows that, for some users, a demo was not sufficient for training and some further instruction was required. The extended usability specification indicates that requiring 'some further instruction' is still acceptable, however, examining the further instruction that was required will point to device improvements. Examples of the further instruction that was required are as follows:

- User J: trying to stop user performing rowing action when moving forward
- User E: further demo of forward move and request to try to be more gentle with device
- User A: further demo of side-step given
- User M: further demo of forward move

The above points indicate that the forward move function of VR1 could be made more obvious, so that a second demonstration would not be required. This could be achieved by employing the following device attributes: 'form indicates function' and 'colour and symbol cues to function'. The same device attributes can also be applied to the side-step function to make it more obvious to the user. A further point about side-step is that there are no tasks in the virtual factory or supermarket that can only be achieved with side-step. There are tasks that would be quicker with side-step, e.g. aligning with the cupboard in the virtual factory, but initially, the user would need to become competent with this function. The user would also need to be shown that side-step can be used as an alternative to perform certain navigation tasks.

Users J and E could only use 1 function during the initial test. User J could use forward move and User E could use left/right turn. User J was quite hesitant (possibly due to under confidence) during the evaluation and therefore may have been able to use more functions with encouragement. This aside, many functions of VR1 need to be made more obvious to these users, by incorporating the aforementioned device attributes of 'form indicates function' and 'colour and symbol cues to function'.

The only user to take longer than the planned time, of 3 sessions, to learn the functions of VR1 was User J. This user performed an unusual rowing action when moving forward until the end of session 4. Overall, the device learning time was satisfactory.

Successful obviousness results

User Y was able to use the primary navigation functions and the interaction part of VR1 without the planned demonstration. Users L, N and I had learned the functions of the device in less than the planned three sessions, with User I only taking one session. For these users no further instruction was needed. These good obviousness results could be due to the relevant device attributes, which the VR1 prototype has met. These device attributes are listed in Table 49.

Conclusion

10 users found VR1 very obvious, whereas 6 found this VE input system less obvious and required further instruction. Hence, there is room for improvement in the obviousness of VR1. Table 49 (the obviousness conclusion table) details how VR1 should be refined to improve this usability attribute.

Table 49. Obviousness conclusion table

Device attributes met – VR1	
• Form indicates interface • Colour cues to interface (different colour from rest of prototype) • Form indicates function (turn left/right) • Colour cue to function (turn left/right) • Form indicates device orientation • Movement in VE same as user action • Navigation and interaction functions in one device • Slots/guides to assist user action (interaction guide plate)	
Device attributes NOT met – VR1	
• Form indicates function (for forward, back, side-step, pitch and cursor control) • Colour and symbol cues to function (for forward, back, side-step, pitch and cursor control) • Buttons form invites user to actuate it • Lights up, makes noise and haptic sensation with use action (feedback)	
Obviousness difficulties – VR1	**Refinement – VR1**
Forward, back and side-step functions not obvious enough for some users	*Form indicates function; Colour and symbol cues to function (for forward, back and side-step)*

9.2.3 Questionnaire 1 (Q1) - usability of VR1

This questionnaire (see Appendix M) was completed with the user group, by interview, to gain their perspective on the usability of VR1. The questions were set at a level that the user group would understand, using symbols to depict the questions graphically. The ISO 9241-9 European Standard (requirements for non-keyboard input devices) states that the main indicators of usability are: effectiveness, efficiency and satisfaction. The questions in Q1 were based on these usability indicators and were as follows:

1. Do you like using VR1?
2. Is using VR1 easy?
3. Is using VR1 tiring?
4. Is using VR1 comfortable?
5. Is using VR1 fun?

Results

The users chose their answer to each question from a rated scale. For example, the choice of answers to the first question were (rating in brackets): really don't like (0), don't like (1), ok (2), quite like (3), like (4) and really like (5). Table 50 lists the planned usability answers and their rating values.

Table 50. Planned usability answers and rating values

Question	Planned Usability	Rating
Like	Like	4
Easy	Easy	5
Tiring	Ok	3
Comfortable	Comfortable	5
Fun	Fun	5
	Planned usability total (= 100%)	**22**

The planned usability total of 22 was used to calculate the % PU for each user's questionnaire answers. These percentages are depicted in Chart 3.

A simpler version of Q1 (entitled Q1b) was available for users who found it difficult to select an answer from the rating scale (see Appendix M). The alternative was to answer either yes or no to the same questions. Table 51 lists a summary of the results of Q1 (or Q1b). The full results are detailed in Appendix M.

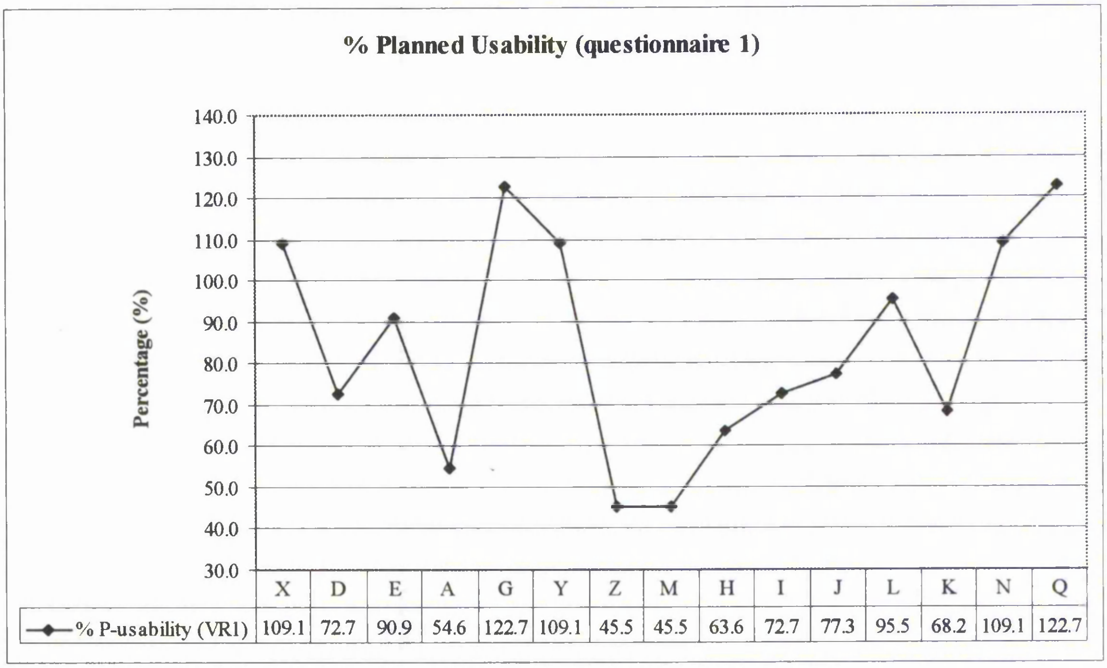


Chart 3. % of planned usability for VR1 from questionnaire 1

Table 51. Summary of Q1 results (usability of VR1)

No. users	% usability	Answers	Understood?
2	45.5	Don't like (1); hard (2); very tiring (1); quite uncomfortable (1); quite boring (1)	Not sure
1	54.6	Very tiring; very boring	Fun result questionable
2	63 – 69	Hard (1); quite uncomfortable (1); boring (1)	Answers not vary
3	72 – 78	Tiring (1); very uncomfortable (1); boring(1)	Yes; answers not vary
2	90 – 96	Tiring (1)	Mostly; Yes
3	109.1	Quite tiring (1); really like (2); very easy (2); very comfortable (1); great fun (2)	Yes
2	122.7	Really like (2); very easy (2); very comfortable (2); great fun (2)	Think so; yes

Discussion

Uncertainty of results

Column 4 of Table 51 indicates whether the author thought that the user understood the questions of Q1 and gave his/her true answers. This column shows that the author was not sure that all of the users did understand the questions. For example, 'fun result questionable' was noted, as this particular user had appeared to enjoy using VR1, during the evaluation sessions. Additionally, some users did not vary their answers and, for example, only selected the answer with the highest rating.

How to improve usability?

For the 8 users who rated VR1 as 80 % of planned usability or less, usability needs to be improved. The most common problem noted was that the users found VR1 tiring to use. This could be improved by employing the following device attributes: 'returns to centre position' and 'smooth operation/action'. The users may have answered that VR1 was tiring as it does require more physical exertion than the joystick. This is because the user's upper body (torso) follows the direction of navigation movement. However, there are possible benefits of this upper body movement, such as: increased sense of immersion within the VE; physiological exercise and improvement of spatial and directional awareness.

Some pupils answered that they found VR1 hard, uncomfortable and boring to use. The examination of all the usability attributes will reveal ways to make VR1 easier to use. As VR1 has foam grips the discomfort is probably not due to gripping the device. Possible reasons for discomfort are the physical exertion required and not being able to sufficiently rest the arm when using the cursor control. This second point could be improved by meeting the device attribute (from the design specification) 'ergonomic design of muscle support'.

Acceptable usability answers

Acceptable usability results were obtained by 7 pupils, 5 of which were above planned usability. The users who rated VR1 above the planned usability gave the following positive results: really like, very easy, very comfortable and great fun.

Conclusion

Baring in mind the uncertainty of Q1's results, there is definitely room for improvement in the usability of VR1, particularly by making this device less tiring, more comfortable and easier to use.

9.3 COMPARISON OF USABILITY OF VR1 AND JM

9.3.1 Overall usability

Results

Chart 4 displays the % PU for each user for both VE input systems. These percentages represent overall usability, which is the sum of the usability attributes of compatibility, efficiency, effectiveness, satisfaction, biomechanical load and controllability. A brief glance at Chart 4 clearly shows VR1 at a higher level and therefore greater usability than JM. More detailed examination of this chart reveals that for one user, subject H, the JM system has greater usability and for three users both systems have the same usability.

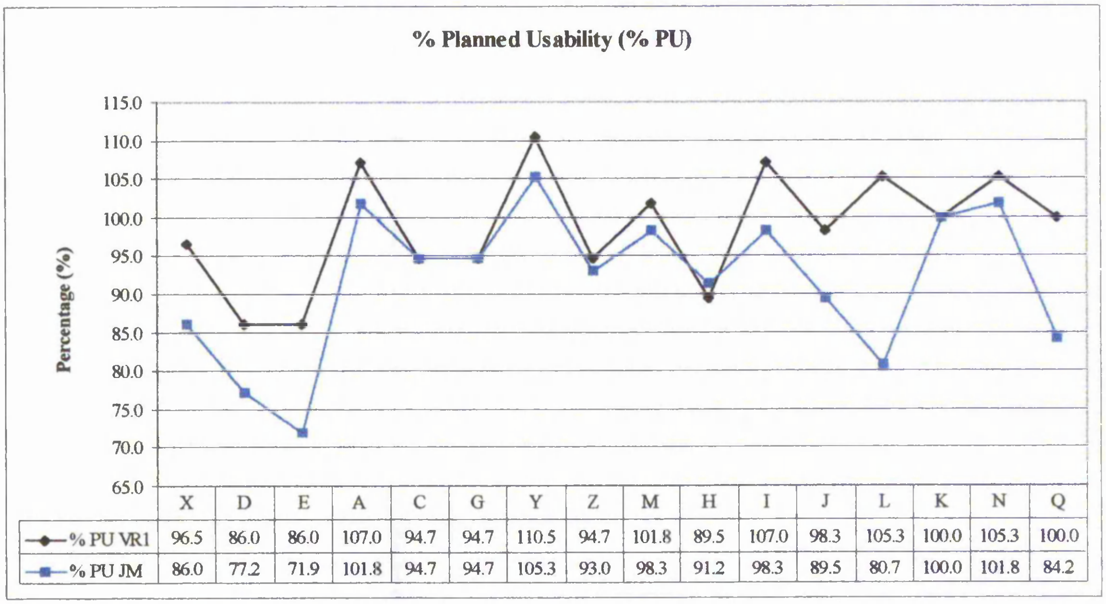
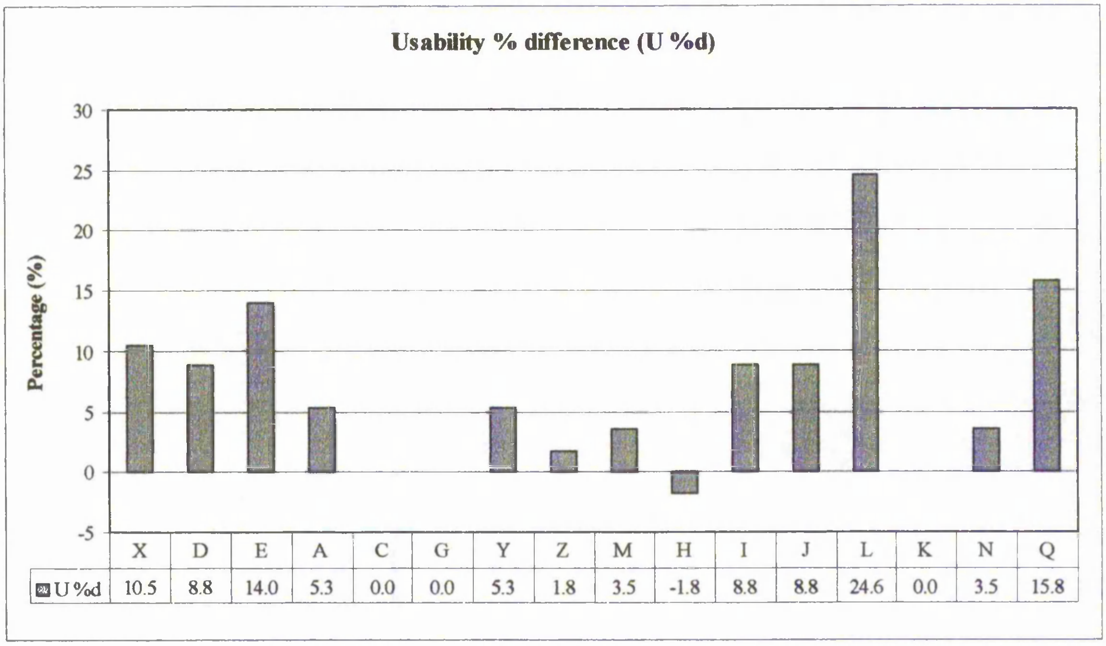


Chart 4. % of planned usability

Table 52. Results summary of overall usability

No. of users	% difference	Description
1	1.8	JM 1.8 % greater usability than VR1
3	0	Usability the same for both VE input systems
3	1 - 4	VR1 between 1 and 4 % greater usability than JM
3	5 - 9	VR1 between 5 and 9 % greater usability than VR1
3	10 - 16	VR1 between 10 and 16 % greater usability than JM
No. of users	**Description**	
1	Usability of JM > VR1	
3	Usability of JM = VR1	
9	Usability of VR1 > JM	

Chart 5 depicts the percentage difference of overall usability between the two VE input systems, with a positive percentage favouring VR1 and a negative percentage favouring JM. This chart also clearly shows that in general, VR1 has increased usability over JM. A summary of the results is listed in Table 52.



	X	D	E	A	C	G	Y	Z	M	H	I	J	L	K	N	Q
U %d	10.5	8.8	14.0	5.3	0.0	0.0	5.3	1.8	3.5	-1.8	8.8	8.8	24.6	0.0	3.5	15.8

Chart 5. % difference in planned usability of the VE input systems

Statistical analysis results

Using the Wilcoxon matched pairs signed-ranks test, the results of the comparison of the usability of VR1 and JM were found to be highly significant, with $P = 0.008$.

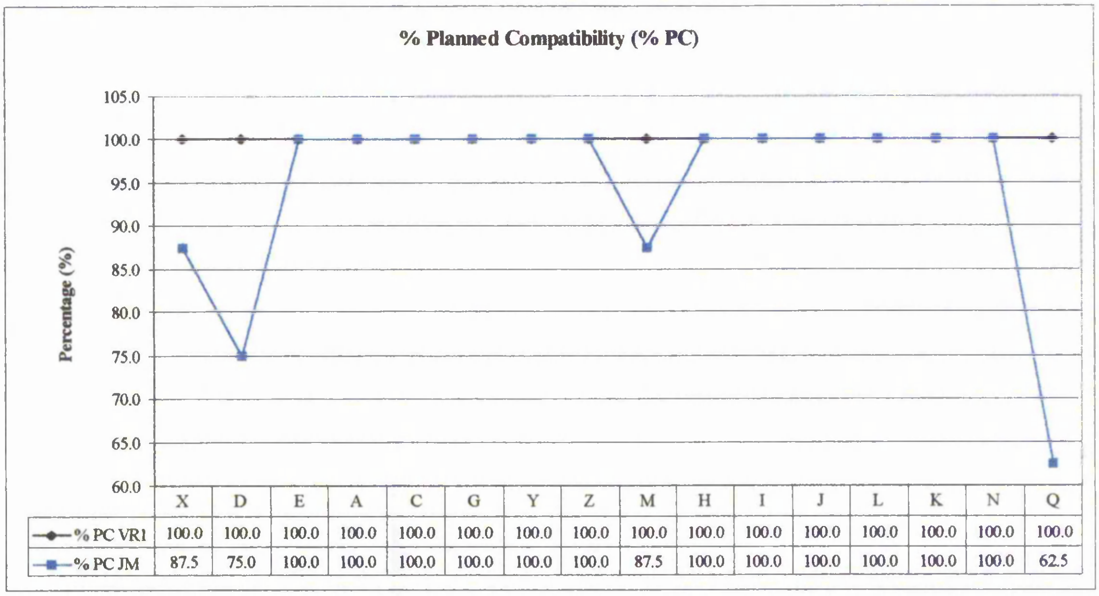
Conclusion

From the results of the % PU it can be concluded that VR1 has greater usability than JM for the majority of subjects tested, by a maximum of 15.8 %. Examining the performance results of the attributes of usability will identify more specific details on how VR1 has greater usability than JM. The results of the comparison of the usability of VR1 and JM were found to be highly significant ($P = 0.008$).

9.3.2 Compatibility

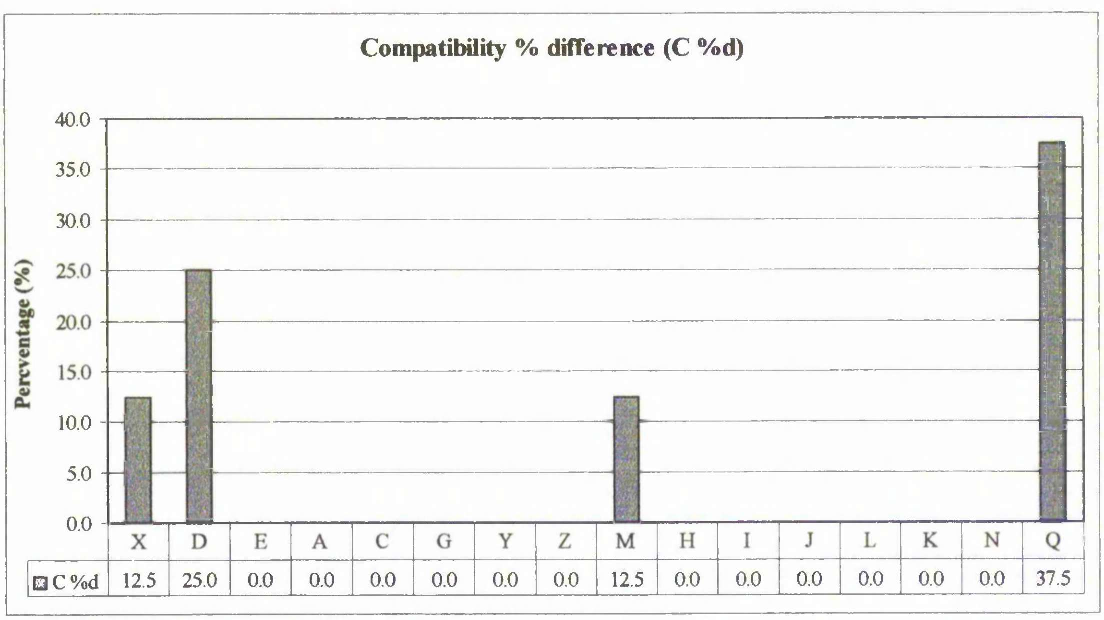
Results

Chart 6 shows the % P-compatibility for each user for both systems. The first result to note is that VR1 is 100 % compatible for all users tested. Although the JM system is also 100 % compatible for many users, Chart 6 clearly displays the drop in percentage compatibility for 4 subjects. The percentage difference in compatibility is shown on Chart 7 and a summary of the results is listed in Table 54.



	X	D	E	A	C	G	Y	Z	M	H	I	J	L	K	N	Q
% PC VR1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
% PC JM	87.5	75.0	100.0	100.0	100.0	100.0	100.0	100.0	87.5	100.0	100.0	100.0	100.0	100.0	100.0	62.5

Chart 6. % of planned compatibility



	X	D	E	A	C	G	Y	Z	M	H	I	J	L	K	N	Q
C %d	12.5	25.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	37.5

Chart 7. % difference in planned compatibility of the VE input systems

Table 54. Summary of compatibility results

No. of users	% difference	Description
8	0	Compatibility the same for both VE input systems
2	12.5	VR1 12.5 % greater compatibility than JM
1	25	VR1 25 % greater compatibility than JM
1	37.5	VR1 37.5 % greater compatibility than JM
No. of users	**Description**	
8	Compatibility of JM = VR1	
5	Compatibility of VR1 > JM	

The usability attribute compatibility was measured by anthropometric and biomechanical difficulties. Anthropometric measures include size of device or device parts, user reach and grip ability, whereas, strength, control and range of movement (ROM) are biomechanical observations. Table 55 describes the compatibility difficulties observed with the JM system.

Table 55. Compatibility difficulties with JM system

User	% < VR1	Difficulties
X	12.5	AN: joystick and mouse both slightly too big for his hands
M	12.5	AN: uncomfortable grip on mouse (finger in air when grip)
D	25	AN: joystick and mouse both slightly too big for his hands; not easy to grip mouse (weaker grasp)
Q	37.5	AN: uncomfortable grip on mouse; BI: movements with mouse quite shaky

Notation for Table 55: AN = anthropometric difficulty; BI = biomechanical difficulty

Statistical analysis results

Using the Wilcoxon matched pairs signed-ranks test, the results of the comparison of the compatibility of VR1 and JM were not found to be significant, with $P = 0.068$.

Discussion

JM compatibility

The only biomechanical difficulty listed in Table 55 is User Q's shaky movements with the mouse. The user analysis of physical ability identified that this user naturally has quite shaky movements (see Table 6, Chapter 3). However, as the mouse is not anchored to a base and is free to move in any direction, no help is offered by this device to control this user's movements. The anthropometric problems that were identified are all grip difficulties:

- The grip that Users M and Q had on the mouse looked uncomfortable, with User M observed to have one finger raised.
- The joystick was observed to be too thick and the mouse too wide for Users X and D.
- User D was observed to have more difficulty obtaining a firm grip on the mouse than on the cursor control handle of VR1. This was probably due to the type of grip required: the cursor control handle on VR1 requires a power grip, whereas, the mouse is gripped with the fingertips. It is stated in ergonomics literature that the grasping force is 4 times greater when clasping with the whole hand than when holding with the fingertips (Kroemer and Grandjean, 1997).

VR1 compatibility

The VR1 prototype was designed from a design specification that was partly the result of a detailed analysis of the user group's physical ability (see Table 5 & 6, Chapter 3). The fact that the compatibility difficulties observed with JM were not found with VR1 suggests that the user-centred design activity 'analysis of user group physical ability' has helped to produce a more compatible VE input system.

Further compatibility observations

Further shaky movements were observed with both systems, but they were not considered severe enough to be counted against compatibility. When using VR1, User G's hand was observed to shake slightly as she approached the interaction button. As with User Q, this user was identified as having 'unsteady arm movement' during the physical ability analysis. Employing the device attribute 'ergonomic design of muscle support' (for the interaction functions of VR1) could help to reduce this difficulty. For the JM system, one user had a slightly shaky hand when using the joystick.

Reaching both VE input systems was observed to be a problem for User D because he was in a wheelchair. Despite JM being positioned at the edge of the work surface, his control with these devices was impeded due to reach difficulties. VR1 had to be held in position by the test administrator, supported on the user's wheelchair arms so that he could access all functions easily. These reach difficulties have not been counted against compatibility as they have been noted under 'positioned easily' in the controllability attribute of usability.

Conclusion

The fact that the compatibility difficulties observed with JM were not found with VR1 suggests that the user-centred design activity 'analysis of user group physical ability' has helped to produce a more compatible VE input system. The results of the comparison of the compatibility of VR1 and JM were not found to be significant (P = 0.068). Table 57 (the compatibility conclusion table) details how VR1 could be refined to further increase the compatibility of this device.

Table 57. Compatibility conclusion table

Device attributes met – VR1	
• Colour – not red or green (appropriate for colour blind) • Ergonomic design of user interface • Ergonomic design for operation whilst sitting • No fine finger operation required • Ergonomic design of muscle support (for navigation) • Designed for one person to use • Sensitivity control function (able to adjust threshold) • Provides assistance to use actions (interaction guide plate) • Will not detect unintentional movement, i.e. tremor (by adjusting threshold)	
Device attributes NOT met – VR1	
• Operated – left or right hand/arm • Ergonomic design of muscle support (for interaction) • Light enough to carry for adult or older pupil • Accepts enthusiastic operation; robust construction	
Compatibility difficulties – VR1	**Refinement – VR1**
User's hand was observed to shake slightly when approaching the interaction button	*Ergonomic design of muscle support (for the interaction functions of VR1)*
Compatibility difficulties – JM	
• User movements with mouse quite shaky • Quite difficult for user to grip mouse • Uncomfortable grip on mouse • J and M a bit too big for user's hand • User had a slightly shaky hand when using the joystick	

9.3.3 Efficiency

Results

A device is most efficient when it functions with the least amount of time and effort. Chart 8 displays the % P-efficiency for each subject for each system. On first glance at this Chart it is difficult to tell which system is more efficient. A clearer picture is depicted in Chart 9, the percentage difference between the two systems, where a greater number of positive percentages than negative indicate VR1 to have a slight efficiency advantage over JM. Table 58 summarises the efficiency results for VR1 and Table 59 summaries the comparison of the two systems.

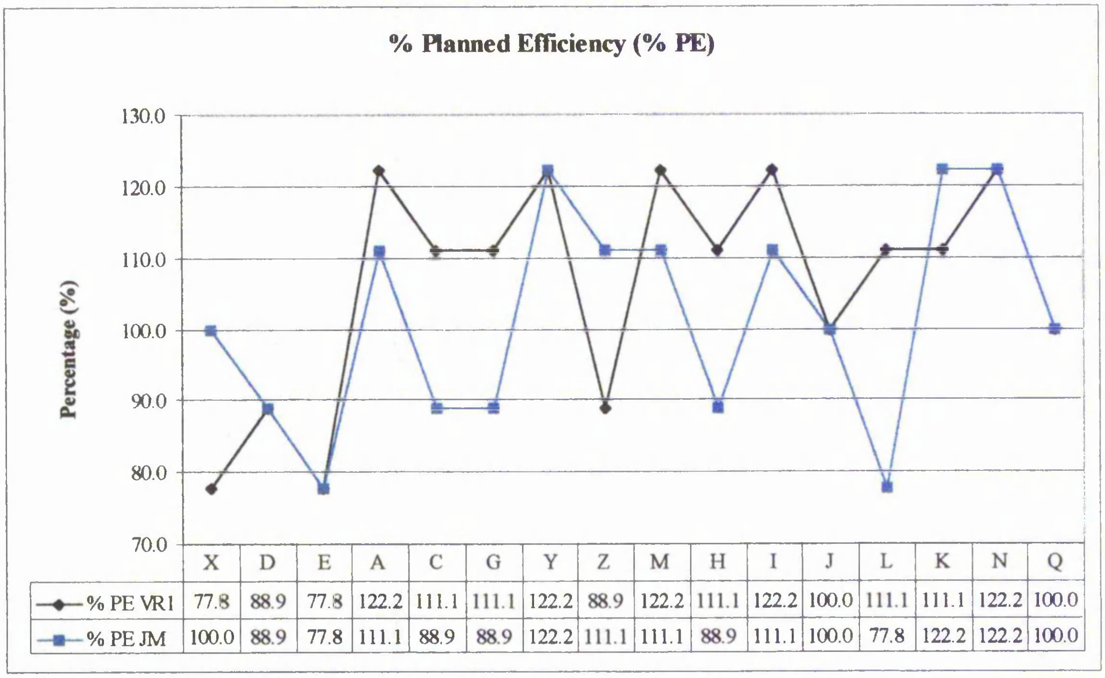


Chart 8. % of planned efficiency

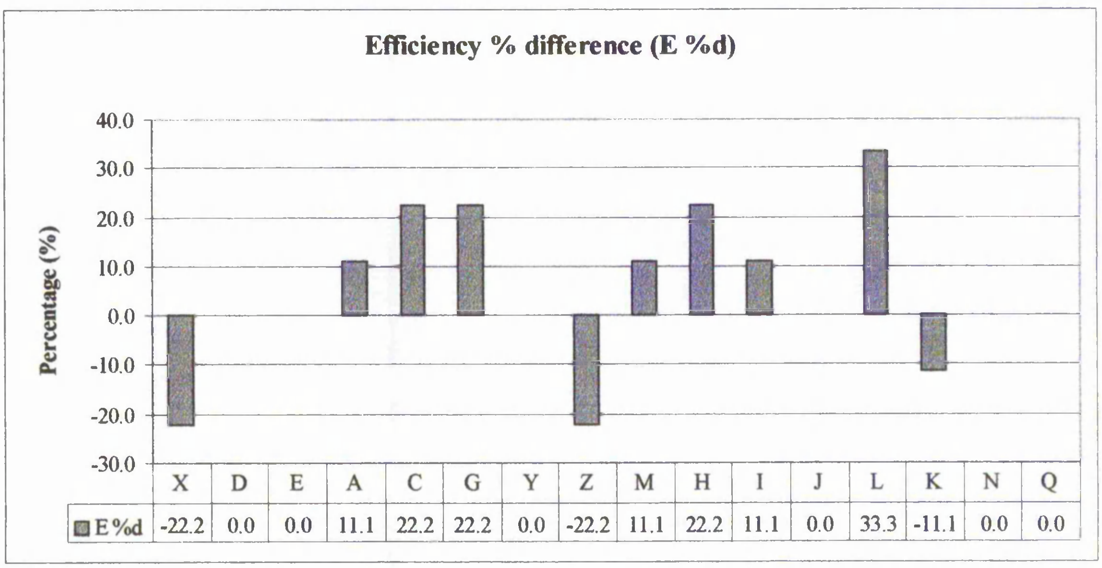


Chart 9. % difference in planned efficiency of the VE input systems

Table 58. Summary of VR1 efficiency results

No. of users	% efficiency	Description
2	77.8	22.2 % less than planned efficiency
2	88.9	11.1 % less than planned efficiency
1	100	Same as planned efficiency
4	111	11 % greater than planned efficiency
4	122	22 % greater than planned efficiency

Table 59. Summary of efficiency comparison

No. of users	% difference	Description
2	22	JM 22 % greater efficiency than VR1
1	11	JM 11 % greater efficiency than VR1
5	0	Efficiency the same for both VE input systems
2	11	VR1 11 % greater efficiency than JM
3	22	VR1 22 % greater efficiency than JM
No. of users	**Description**	
3	Efficiency of JM > VR1	
5	Efficiency of JM = VR1	
5	Efficiency of VR1 > JM	
System	**Lowest %**	**Highest %**
VR1	77.8	122
JM	77.8	122

Table 58 shows that 9 pupils scored equal to or greater than planned efficiency with VR1 and only 4 scored less than planned efficiency. Table 59 details that the lowest % efficiency for both systems was found to be 77.8 %, which is still a reasonably good result. Hence, these statements indicate that both VR1 and JM were found to be quite efficient. Table 59 also shows the marginal efficiency advantage that VR1 was observed to have over JM.

Table 60. Comparison of VR1 and JM efficiency results

User	% < JM	-	Task time	Harshness	Effort	JM advantage
Z	22	JM VR1	Quite fast Average	None Minimal	Minimal (J align) Minimal (I manip)	Faster task time; no harshness
X	11	JM VR1	Quite fast Average	Some Some	Minimal (energy) Minimal (I)	Faster task time
K	11	JM VR1	Quite fast Average	None None	None None	Faster task time
User	**% < VR1**	**-**	**Task time**	**Harshness**	**Effort**	**VR1 advantage**
C	22	JM VR1	Average Average	None None	Yes (J manipulation) None	No effort to use
G	22	JM VR1	Average Average	None None	Yes (J manipulation) None	No effort to use
H	22	JM VR1	Average Average	None None	Yes (J manipulation) None	No effort to use
A	11	JM VR1	Average Quite fast	None None	None None	Faster task time
M	11	JM VR1	Quite fast Quite fast	None None	Minimal (J manip) None	No effort to use

Notation in effort column (Table 60):

- J = joystick and I = cursor control handle (VR1)

The metrics of efficiency were: time to complete the evaluation tasks; harsh use of a device and effort displayed in using a device. Table 60 compares a selection of the efficiency results to identify the advantages and difficulties of each system. Table 61 lists the results of the remaining lower efficiency percentages to identify any further system difficulties.

Table 61. Lowest VR1 and JM efficiency results

VR1					
User	% efficiency	Task time	Harshness	Effort	Improve
E	77.8	Average	Some (I)	Minimal (I)	I control; harsh use
D	88.9	Quite slow	None	Minimal (L/R turn)	L/R turn easier; task time
Joystick and mouse (JM)					
User	% efficiency	Task time	Harshness	Effort	Improve
E	77.8	Quite slow	None	Yes (J & M manip)	J & M manipulation; task time
D	88.9	Quite slow	None	Minimal (M button)	Button actuation; task time

Notation in harshness, effort, and improve columns (Table 61):

- J = joystick, M = mouse and I = cursor control handle (VR1)

Statistical analysis results

Using the Wilcoxon matched pairs signed-ranks test, the results of comparison of the efficiency of VR1 and JM were not found to be significant, with P = 0.363.

Discussion

<u>*VR1 efficiency*</u>

Effort

Table 60 and 61 indicate that less effort was required to use VR1. Users Z, X and E displayed minimal effort in controlling the cursor handle. 5 different speeds were available for cursor control. When set at the fastest speed, effort was required by some pupils to position the cursor on smaller VE objects. When set at the slowest speed, less effort was required. This effort could be reduced by increasing the resistance to movement of the cursor control and replacing the 5-speed function with just 2 speeds: a faster speed for positioning on large VE objects and a slower speed for positioning on small VE objects. The 2-speed function would enable a user to quickly select the required speed for the interaction task. Minimal effort was required by User D to turn left and right using VR1. This difficulty could be improved by reducing the threshold value of this function so that the VE responds to a smaller user movement.

Three further effort difficulties, not noted in Tables 60 and 61, were also observed. Three users were noted to move the cursor handle of VR1 excessively in each direction. Increasing the resistance to movement of the cursor handle would help to reduce this problem. Three users were recorded to move the device excessively for turning left and right. Future refinement would involve limiting the distance that the user can turn the handles, increasing the resistance to movement and training the subjects to use smaller movements to turn. Finally, one subject used unnecessary effort to access the interaction button, by bending his arm over the top of VR1 and approaching from the back of the device. This user could be taught to access the button more directly.

Harshness

Table 60 and 61 indicate that more harshness was observed with VR1 than with the JM system. User Z was quite tense when using VR1, gripping the handlebars of the device tightly and this observation was noted as minimal harshness. Further practice with VR1 may help User Z to relax when using the device and hence stop any harsh use. User E was noted to be harsh with the cursor handle. However, it has already been pointed out that this user displayed effort in using the cursor handle, which could have been the cause of the harsh use. Hence, improving this user's control of the cursor handle could result in reduced harshness.

A further harshness difficulty, not included in Tables 60 or 61, was noted: 2 further users were observed to be quite forceful with the cursor handle, which, for one of these users, quite often resulted in missing the target (overcompensating). One user was harsh when navigating with VR1 and actually broke the device on his first attempt when he turned too far to the right (see previous chapter: VR1 prototype adjustment).

Task time

The first section of Table 60, which looks at how JM was found to be more efficient than VR1, highlights that these users achieved faster task completion using JM. However, the combined details of Table 60 and 61 suggest that task time with VR1 was 'average' in most cases, which is actually the planned case for this measure (see extended usability specification) and is therefore acceptable. Task time will automatically be reduced by attending to any future system refinements that increase ease of use.

Possible reason for JM task time advantage: the mouse was observed to be quicker to use, for the users who were able to use both the mouse and the cursor handle of VR1 quite proficiently for interaction. This is because the user can move the cursor more directly and more immediately to the target using the mouse, almost as if the device is part of the hand. Whereas, with the cursor handle, cursor positioning is controlled from the handle (which is less direct) and is limited to the speed at which the function is set.

JM efficiency

Effort

Table 60 and 61 indicate that the main cause of excessive effort with the JM system was joystick manipulation, e.g. for VE alignment tasks. Additionally, effort was required by User E to use the mouse and by User D to actuate the mouse button. A further effort difficulty that is not detailed in table 60 or 61 is that three users were observed to move the joystick excessively in each direction. This resulted in reduced control of navigation, as the further the joystick is moved the faster the VE responds.

Harshness

The only harshness observed with JM was by User X. However, this user was quite rough with both systems, which suggests that the harshness could be the result of his over exuberance rather than the design of either VE input system.

Task time

As stated previously, some users achieved faster task completion using JM. However, table 62 shows that quite slow task times were also recorded with JM. If the effort difficulties with this system are solved, this should result in reducing user task time.

Two further efficiency difficulties, not included in Table 60 or 61, were observed that would effect task time. Three users were noted to position the cursor quite slowly using the mouse and two users moved the joystick slowly. Although these users were able to complete the required tasks eventually, improvement to their interaction and navigation speed would reduce overall task time and hence efficiency.

Conclusion

Both VR1 and JM were found to be quite efficient, with VR1 having a slight efficiency advantage over JM. Improvement is required with the efficiency measures of effort and task time for both systems. Suggested VR1 refinement to improve efficiency is listed in Table 63 (the efficiency conclusion table). The results of the comparison of the efficiency of VR1 and JM were not found to be significant ($P = 0.363$).

Table 63. Efficiency conclusion table

Efficiency difficulties – VR1	Refinement – VR1
Minimal effort to turn left and right	*Reduce the threshold value for turn left and right*
Part-N moved excessively for turning left and right	*Increase resistance to movement for left/right turn* *Limit the distance for left/right turn*
Part-N of device broke with excessive right turn	*Robust construction*
Minimal effort to control the cursor function	*Increase the resistance to movement of the cursor function; incorporate 2 cursor speeds – one fast and one slow*
Cursor control moves excessively in each direction	*Same as above*
Efficiency difficulties – JM	
• Effort required with joystick manipulation, i.e. for alignment tasks • Users moved joystick excessively in each direction • Slow use of joystick • Effort required to use mouse • Effort required to actuate mouse button • Slow cursor positioning using mouse	

9.3.4 Effectiveness

Results

The users' % P-effectiveness for both systems are plotted on Chart 10, with the percentage differences on Chart 11. As with efficiency, it is difficult to obtain a clear winner of effectiveness with a glance at Chart 10. Chart 11 reveals that 8 pupils found VR1 more effective to 5 finding JM more effective. Table 64 summarises the effectiveness results for VR1 and Table 65 summarises the comparison of the two systems.

For VR1, good effectiveness results were recorded for 8 pupils (see Table 64). These pupils scored equal to or greater than planned effectiveness. 5 pupils scored less than planned effectiveness, with a lowest percentage of 76.9. Hence there is room for improvement in the effectiveness of VR1 for some users. Table 65 shows that VR1 was observed to be marginally more effective than JM. This table also details that the lowest result for JM is 61.5 %, which is quite low.

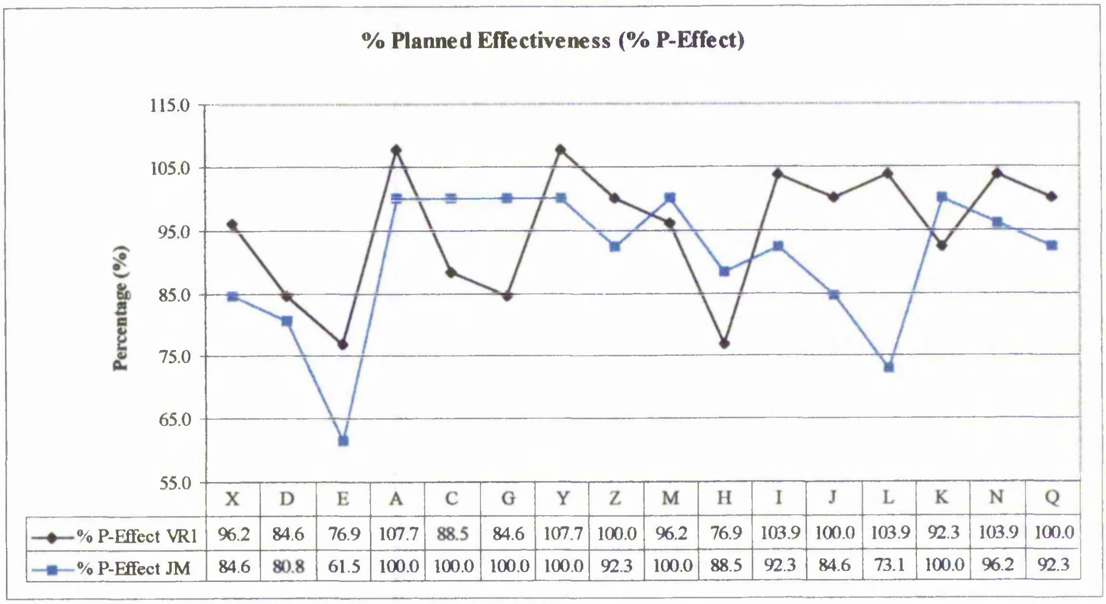


Chart 10. % of planned effectiveness

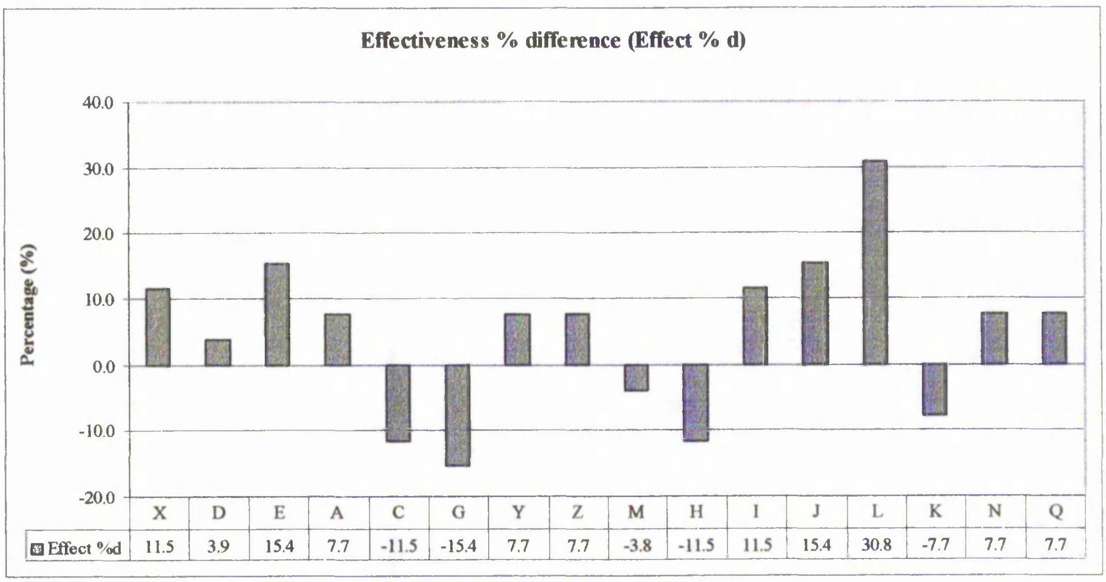


Chart 11. % difference in planned effectiveness of the VE input systems

Table 64. Summary of VR1 effectiveness results

No. of users	% effectiveness	Description
2	76.9	23.1 % less than planned effectiveness
2	84 – 89	Between 11 and 16 % less than planned effectiveness
1	92 – 97	Between 8 and 3 % less than planned effectiveness
4	100	Same as planned effectiveness
4	103 – 108	Between 3 and 8 % greater than planned effectiveness

Table 65. Summary of effectiveness comparison

No. of users	% difference	Description
3	11 – 15.5	JM between 11 and 15.5 % greater effectiveness than VR1
1	7.7	JM 7.7 % greater effectiveness than VR1
1	3.9	JM 3.9 % greater effectiveness than VR1
1	3.9	VR1 3.9 % greater effectiveness than JM
5	7.7	VR1 7.7 % greater effectiveness than JM
2	11 – 15.5	VR1 between 11 and 15.5 % greater effectiveness than JM
No. of users	**Description**	
5	effectiveness of JM > VR1	
8	effectiveness of JM = VR1	
System	**Lowest %**	**Highest %**
VR1	76.9	107.7
JM	61.5	100

The effectiveness metrics were: unproductive device and task actions; disorientation; verbal and physical support; task completion and use after training. Table 66 compares a selection of the effectiveness results to identify the advantages and difficulties of each system. Table 67 lists the results of the remaining lower effectiveness percentages to identify any further system difficulties.

Table 66. Comparison of VR1 and JM effectiveness results

User	% < JM	VR1 disadvantage	JM advantage
G	15.4	Disorientation, support verbal, support physical (minimal, pitch)	No disorientation, support verbal or physical
C	11.5	Large N moves, disorientation (pitch), support physical (pitch)	No unproductive actions-device, disorientation or support physical
H	11.5	I for navigation and pitch for forward, disorientation (pitch)	No unproductive actions-device or disorientation
User	**% < VR1**	**JM disadvantage**	**VR1 advantage**
E	15.4	Random movement with J and M; support verbal (J button); lower task completion, use some functions	No unproductive actions-task, less verbal support, greater task completion, can use primary functions
X	11.5	Disorientation (J button), support physical (rectify pitch), not use as well	No disorientation and support physical, can use well
A	7.7	Full and jerky movement of joystick, can use only primary functions	No unproductive actions-device, can use well (primary and secondary)

Table 67. Lowest VR1 and JM effectiveness results

VR1		
User	**% effect.**	**Improve**
E	76.9	Overcompensation with I; disorientation (pitch); physical help (positioning cursor, stopping at target)
H	76.9	I for navigation and pitch for forward; look wrong way with pitch; disorientation (pitch); support verbal (encouragement); support physical (rectify pitch)
Joystick and mouse (JM)		
User	**% effect.**	**Improve**
E	61.5	Twisting M to left; random movement (J and M); disorientation (pitch); physical support (I and N tasks, rectify pitch); use only some functions
D	80.8	Disorientated (into wall once); support physical (out of corner and some alignment)

Statistical analysis results

Using the Wilcoxon matched pairs signed-ranks test, the results of comparison of the effectiveness of VR1 and JM were not found to be significant, with $P = 0.675$.

Discussion

<u>*VR1 effectiveness*</u>

Unproductive device actions

User H tried to use the cursor handle for navigation tasks and the look up/down function for moving forward. It is quite possible that this subject tried to use the cursor handle for navigation because of its similarity to a joystick. The second incorrect action, using look up/down for forward navigation, suggests that achieving forward movement is not obvious enough to the user. The other unproductive device actions noted in Table 66 and 67 have already been covered in the efficiency section. These difficulties are that User C was observed to move the device excessively far in each direction when navigating and User E was noted to overcompensate with the cursor handle.

Two further difficulties, not noted in Table 66 or 67, were also observed. Several subjects used the left/right turn function of VR1 as well as the cursor handle to position the cursor. Future refinement requires increased ease of use of the cursor handle so that users are not tempted to use the navigation functions of VR1 for interaction tasks. The second point observed was that a few users adopted their own method of interacting with the VE. The usual method of interaction is to position the cursor over the VE object and then press the interaction button. These users would press the interaction button whilst the cursor was on the move, which often resulted in the user just missing the VE object. Hence, this method was quite ineffective. These users could be taught how to interact more effectively with the VE using VR1.

Unproductive task actions

Several users were observed to look up, using the look up/down function for a task that required them to look down, which suggests that the mapping of user action to VE reaction is not connecting as planned, for these users. Future development should involve ensuring that the following device attribute is met for the look up/down function of VR1: 'movement in VE same as user action'.

A further difficulty, not noted in Table 66 or 67, was observed. For one particular task (virtual factory: entering the building) User C would navigate away from the target, before completing the task. However, this user was recorded to do the same thing when using the JM system.

Disorientation

In all cases, disorientation was caused by the look up/down function of VR1. During the first evaluation session, with this function active, users would accidentally look down when moving forward. The pupils who were able to rectify the VE position by themselves were not noted for disorientation, but were noted for interference (controllability measure). Due to this look up/down difficulty, it was decided that this function would be removed (for the users who experienced problems) until competency was observed with the primary navigation functions (forward, backward and turn left/right).

Verbal support

As well as the verbal support required by User G for rectifying look up/down interference, consistent encouragement was given to User H during the evaluation. However, as this subject required encouragement to use both systems, it is the author's opinion that this level of support is not reflective of device effectiveness, but rather the subject's under confident nature.

Physical support

Physical support was required by User E for positioning the cursor for some interaction tasks and for stopping next to a task in the VE. This subject's use with the cursor handle was observed to be more on task than his use of the mouse, which he moved randomly. However, future development should focus on increasing the effectiveness of the cursor handle for this user. Stopping next to the VE task would be easier for this user to achieve if the following device attribute had been met: 'returns to centre position'. An attempt was made to employ this device attribute in the VR1 prototype. However, due to the weight of the component parts, the device did not spring back to the centre. It will be easier to incorporate this device attribute in a future prototype that is manufactured using the lightest possible materials.

Task completion

As noted above in physical support, User E required help to complete some interaction tasks. Apart from this, the user group task completion rate was very high, with 5 users achieving >= 90% task completion and 8 users achieving 100% task completion. For those who achieved >= 90%, very minimal assistance with navigation or interaction was recorded.

Use after training

All of the subjects tested were able to use the primary navigation functions and the interaction functions of VR1 after training and the majority of the users displayed understanding of the secondary navigation functions. For a selection of users further practice with the secondary navigation functions, particularly side-step, is required.

JM effectiveness

Unproductive device actions

As noted in Table 67, User E twisted the mouse perpendicular to its normal alignment position. This twisting of the device is not possible with the cursor handle of VR1 as it is attached to the rest of the prototype. The second unproductive device action, which is noted in Table 66, has already been covered in the efficiency section: User A moved the joystick excessively in each direction, in a jerky manner.

A further difficulty, not included in Table 66 or 67, was that two users were observed to repeatedly press the mouse button, when only one press was required to cause interaction.

Unproductive task actions

User B was observed to move the joystick and mouse randomly. This pupil's use of VR1 was much more task orientated for both navigation and interaction. Possible reasons for this are:

- Navigation: VR1 incorporates the cognitive factor (see design specification) 'movement in VE same as user action', which was employed to reduce the cognitive processing required to control navigation.
- Interaction: the cursor handle of VR1 has less degrees of freedom than the mouse. The mouse is free to move in any direction, as it is not attached to a base, whereas, the cursor

handle is attached to VR1 and always springs back to a central position when user force is removed. Additionally, the guide plate can be attached to VR1 to restrict the cursor handle to just horizontal and vertical movement. It was concluded by Hall that reducing the degrees of freedom of a joystick results in fewer navigation errors (Hall, 1993).

Further unproductive task actions, not included in Tables 66 or 67, were observed. User G moved into and along the VE wall and User H clicked in random positions in the VE using the mouse.

Disorientation

The main cause of disorientation in the VE was the joystick button, noted for Users X and E. The positioning of the joystick buttons means that they obstruct the grip for some users and are a distraction for others. If the user presses the top joystick button whilst moving forward this causes 'look down' in the VE, which often leads to disorientation. User D became disorientated when he navigated into a VE wall.

Verbal and physical support

As mentioned in the verbal support for VR1, User H required encouragement to use both systems, due to her under confident nature. Aside from this, very little verbal support was required with JM. In addition to the physical support required by Users X, E and D to rectify disorientation, User E required support to complete some navigation and interaction tasks and User D required some support with alignment to VE objects.

Task completion

As stated above, User E required support to complete some navigation and interaction tasks and User D required some support with alignment to VE objects. Overall, the task completion rate was very high, with 4 users achieving > = 90% task completion and 8 users achieving 100% task completion. As with VR1, for those who achieved >= 90%, very minimal assistance with navigation or interaction was observed.

Use after training

The following points suggest that VR1 tested better for this measure than JM. The first point is that User E was able to use the primary functions of VR1, whereas he was only able to use some functions of JM. Secondly, although User X could use JM, it was observed that he became very proficient with VR1. Finally, User A could use both systems proficiently, but in this case the advantage that VR1 had over JM was accessibility to the secondary navigation movements look up/down and side-step. The reason for this advantage could be that VR1 meets the device attribute 'one user action = one VE function', whereas to control the secondary navigation movements with the joystick, the user has to first press a button and then move the joystick in the required direction.

Conclusion

For VR1, good effectiveness results were recorded for 8 pupils, who scored equal to or greater than planned effectiveness. However, as 5 pupils achieved less that planned effectiveness, there is definitely room for improvement in the effectiveness of VR1 for some users. Overall, VR1 was found to be marginally more effective than JM. For the individual measurements, less unproductive device actions were observed with JM, whereas VR1 tested better for use after training. Table 69 (the effectiveness conclusion table) lists the effectiveness difficulties observed with both systems and details future refinement for VR1. The results of the comparison of the efficiency of VR1 and JM were not found to be significant (P = 0.675).

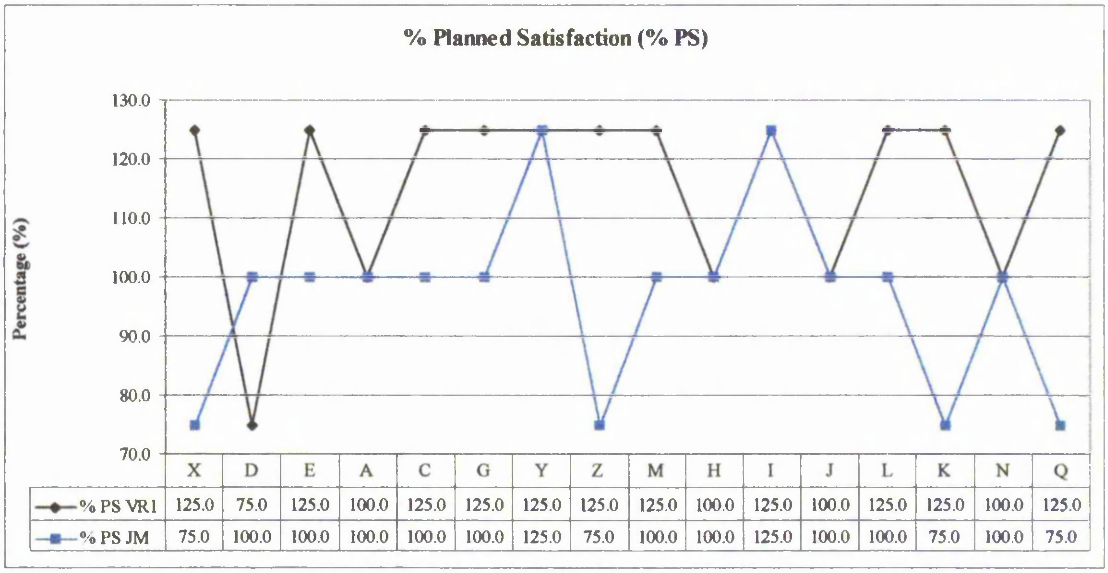
Table 69. Effectiveness conclusion table

Effectiveness difficulties – VR1	**Refinement – VR1**
Tried to use part-I for navigation	*User conceptual model should map to designers (for pitch function)*
Tried to use pitch for forward move	*Form indicates function; colour and symbol cues to function (for forward move)*
Looked wrong way using pitch	*Ensure user action maps to VE movement (pitch)*
Disorientation caused by pitch function	*Ability to switch pitch on/off; research alternative pitch control ideas*
Physical support to stop next to VE object	*Ensure device returns to centre*
Used combination of L/R turn and part-I to position cursor	*Ensure cursor control is easy to use*
User clicked interaction button whilst still moving part-I, 'on the move clicking'	*Train user to stop over VE object before pressing interaction button*
Effectiveness difficulties – JM	
• Joystick button caused disorientation • Quite difficult to use secondary navigation functions • Mouse twisted to left, looks uncomfortable • Repeated pressing of mouse button • Random clicking in VE using mouse • Random movement of joystick and mouse • Only able to use some functions of JM system	

9.3.5 Satisfaction

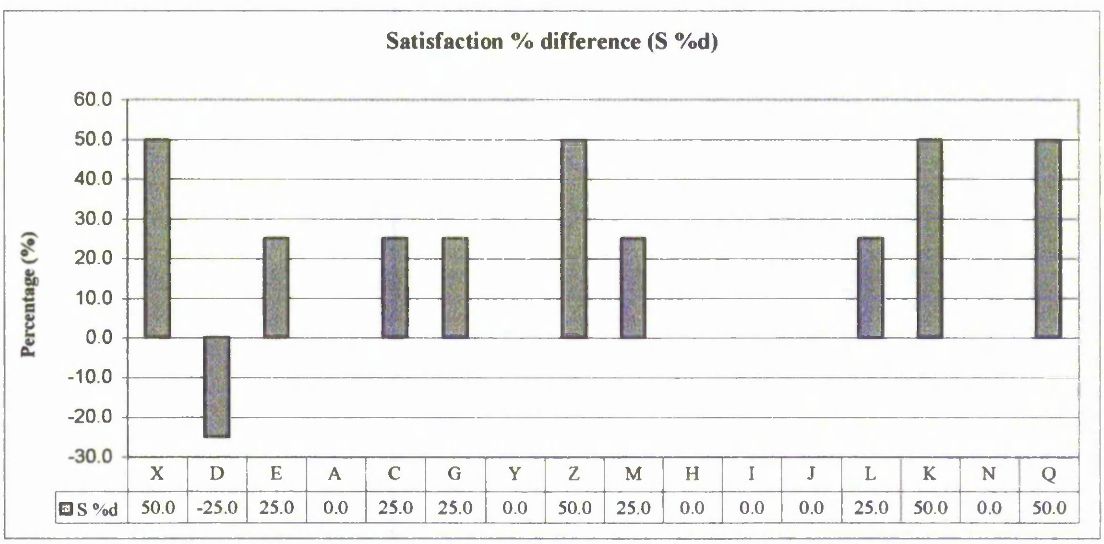
Results

By examining Chart 12, which shows the users' % P-satisfaction for each system, you can see that VR1 has scored higher for satisfaction than JM. This result can also be seen on Chart 13, percentage differences of satisfaction, as the majority of percentages are in favour of VR1. Table 70 summarises the satisfaction results for VR1 and Table 71 summarises the comparison of the two systems.



	X	D	E	A	C	G	Y	Z	M	H	I	J	L	K	N	Q
% PS VR1	125.0	75.0	125.0	100.0	125.0	125.0	125.0	125.0	125.0	100.0	125.0	100.0	125.0	125.0	100.0	125.0
% PS JM	75.0	100.0	100.0	100.0	100.0	100.0	125.0	75.0	100.0	100.0	125.0	100.0	100.0	75.0	100.0	75.0

Chart 12. % of planned satisfaction



	X	D	E	A	C	G	Y	Z	M	H	I	J	L	K	N	Q
S %d	50.0	-25.0	25.0	0.0	25.0	25.0	0.0	50.0	25.0	0.0	0.0	0.0	25.0	50.0	0.0	50.0

Chart 13. % difference in planned satisfaction of the VE input systems

Table 70. Summary of VR1 satisfaction results

No. of users	% effectiveness	Description
1	75	25 % less than planned satisfaction
3	100	Same as planned satisfaction
9	125	25 % greater than planned satisfaction

Table 71. Summary of satisfaction comparison

No. of users	% difference	Description
1	25	JM 25 % greater satisfaction than VR1
4	0	Satisfaction the same for both VE input systems
4	25	VR1 25 % greater satisfaction than JM
4	50	VR1 50 % greater satisfaction than JM
No. of users	**Description**	
1	Satisfaction of JM > VR1	
4	Satisfaction of JM = VR1	
8	Satisfaction of VR1 > JM	
System	**Lowest %**	**Highest %**
VR1	75	125
JM	75	125

Only 2 measures were used to assess the usability attribute of satisfaction. These measures were comfort (did the user look uncomfortable, comfortable or very comfortable) and user attitude (was the user discontent, content or happy). Comfortable and content are the planned results, which give 100% satisfaction and have a total rating value of 4.

Table 72. Selection of satisfaction results

VR1				
User	**% Satis**	**Comfort**	**User attitude**	**Improve**
X	125	Comfortable	Happy	/
E	125	Comfortable	Happy	/
C	125	Comfortable	Happy	/
G	125	Comfortable	Happy	/
D	75	Uncomfortable	Content	Comfort (adaptation for special chair)
Joystick and mouse (JM)				
User	**% Satis**	**Comfort**	**User attitude**	**Improve**
Y	125	Comfortable	Happy	/
D	100	Uncomfortable	Happy	Comfort (JM bit large for hand, not easy grip mouse, reach far for forward move with J)
X	75	Uncomfortable	Content	Comfort (keeps changing grip and JM bit large for hand)
Z	75	Uncomfortable	Content	Comfort (changing grip, front J button in way of grip)
K	75	Uncomfortable	Content	Comfort (mouse grip)
Q	75	Uncomfortable	Content	Comfort (changing grip on J, mouse grip not look comfortable)

Table 70 shows that all users, but one, achieved equal to or greater than planned satisfaction with VR1. Table 71 shows that 8 users were observed to find VR1 more satisfactory, with only 1 observed to find JM more satisfactory. This table also states that 75% is the lowest satisfaction result for both systems. The users who scored 75% have only dropped 1 point on the rating scale, which means they were recorded as either uncomfortable or discontent, but not both. Table 72 shows details of a selection of the satisfaction results (including all the lower percentages) for both systems and points out what needs to be improved to increase satisfaction.

Statistical analysis results

Using the Wilcoxon matched pairs signed-ranks test, the results of comparison of the satisfaction of VR1 and JM were found to be significant, with $P = 0.021$.

Discussion

<u>*VR1 satisfaction*</u>

Comfort

It is stated in Table 72 that User D looked uncomfortable when using VR1. VR1 had to be supported by the test administrator on the arms of this user's wheelchair, so that the user could reach the controls with ease. Future development requires adaptation of VR1 for wheelchair users to increase user comfort.

User attitude

No users were observed to be discontent when using either system. Table 72 indicates that many users appeared to be happy when using VR1. A result of 125% satisfaction was recorded when a user appeared both comfortable and happy. Overall, 9 users achieved 125 % satisfaction with VR1, whereas only 1 user achieved this percentage with the JM system, suggesting that in general the users were more content when using VR1. It is possible that this could be partly attributed to the VR1 prototype being 'new and exciting'. However, previous research suggests that this factor may positively effect device use, as it has been stated that success in learning to use communication devices has also been associated with attitude ratings, such as drive and attitude toward technology (Goodenough-Trepagnier and Felts, 1986). Additionally, Cress and French (1994) report that low motivation to learn a device, however easy it may appear in isolation, is likely to increase the effective difficulty in acquiring adequate device skills.

JM satisfaction

Comfort

Greater discomfort was observed with the JM system than with VR1. As with VR1, User D experienced discomfort with JM due to wheelchair access. Even though the joystick was placed as close to this user as possible, he had to reach uncomfortably far to cause forward movement with the joystick. As stated in Table 72, the joystick and mouse were observed to be a bit too large for the hand dimensions of Users X and D, resulting in a grip that looked uncomfortable. For User Z, obtaining a comfortable grip was impeded by the front joystick button. Finally, the mouse was observed to look uncomfortable to grip by Users K and Q.

User attitude

As stated above no users were observed to be discontent when using either system. However, the satisfaction results suggest that in general the users were more content when using VR1.

Conclusion

The majority of users were observed to have a more positive attitude when using VR1 than when using the JM system and more users appeared to find the JM system uncomfortable. Hence, VR1 was observed to be more satisfactory than JM. Future refinement for VR1 is detailed in table 74 (the satisfaction conclusion table). The results of the comparison of the satisfaction of VR1 and JM were found to be significant ($P = 0.021$).

Table 74. Satisfaction conclusion table

Device attributes met – VR1	
• Modern style, attractive colours • Style – not feminine or masculine • Comfortable form for interface • Comfortable material for interface	
Device attributes NOT met – VR1	
• Comfortable to carry for adult or older pupil • Visual, auditory and haptic feedback	
Satisfaction difficulties – VR1	**Refinement – VR1**
Device had to be supported on user's wheelchair arms	*Adaptation for wheelchair users*
Satisfaction difficulties – JM	
• Front joystick button prevented a comfortable grip on the joystick • Mouse uncomfortable to grip • User has to reach too far for forward movement with joystick • Joystick and mouse too large for user's hand dimensions	

9.3.6 Biomechanical load

This usability attribute was measured by the deviation from a neutral working posture. The posture observations were observed with reference to the hand and wrist postures (Chapter 7, Figure 29: adapted from Pheasant 1996). A chart has not been developed to depict the results for biomechanical load as the results for both VE input systems are virtually the same. The most common result recorded was 'non-harmful deviation' of the wrist. This wrist deviation has been classified as non-harmful as it is very slight, not under a large force and is not repetitive at a high frequency (see Chapter 7: cumulative trauma disorders).

VR1 biomechanical load

For VR1, slight wrist deviation was noted by a few pupils using the look up/down function and by many users for turn left/right. Slight wrist deviation was also observed by one subject using the cursor handle. Although the deviation observed is acceptable, the deviation for turn left/right could be reduced if the users turned their upper body more with the direction of movement. As previously stated, this upper body movement could have therapeutic benefits of increased physiological exercise and enhanced spatial and directional awareness.

JM biomechanical load

Slight wrist deviation was observed by many subjects using the joystick and by one user who twisted the mouse to the left. No deviation was observed for 2 users with JM, as these users controlled the joystick from their elbow joint, rather than from their wrist.

Conclusion: No harmful deviation was observed with either VE input system.

9.3.7 Controllability

Results

The results for controllability are depicted in Charts 14 (% P-controllability) and 15 (percentage differences between the systems). Chart 14 shows a greater number of higher percentages for VR1 than for JM, indicating that VR1 has greater controllability than JM. This is supported by Chart 15, with a greater number of positive percentages than negative. Table 75 summarises the controllability results for VR1 and Table 76 summarises the comparison of the two systems.

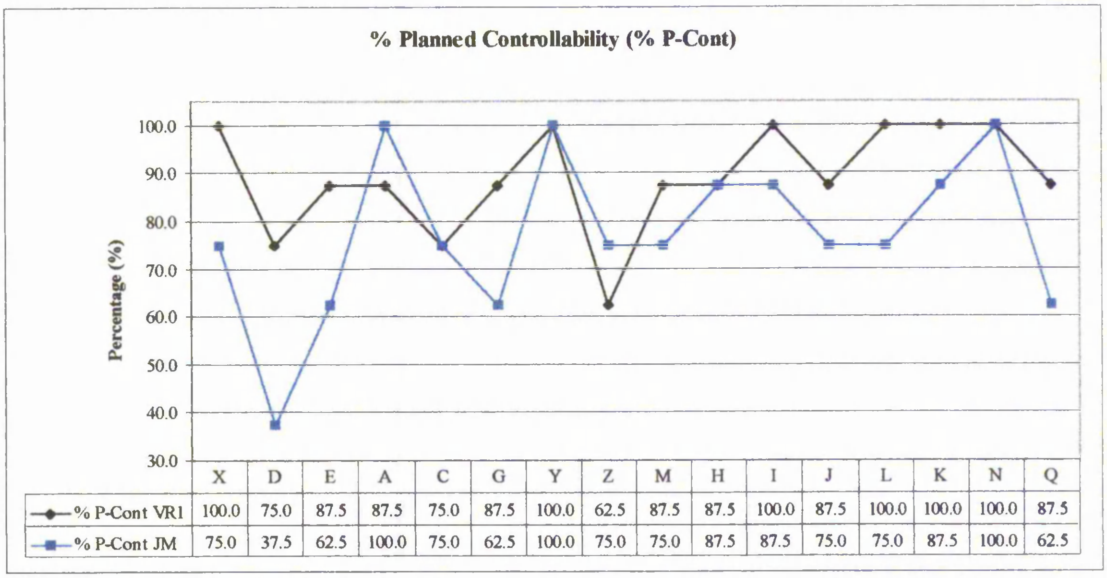


Chart 14. % of planned controllability

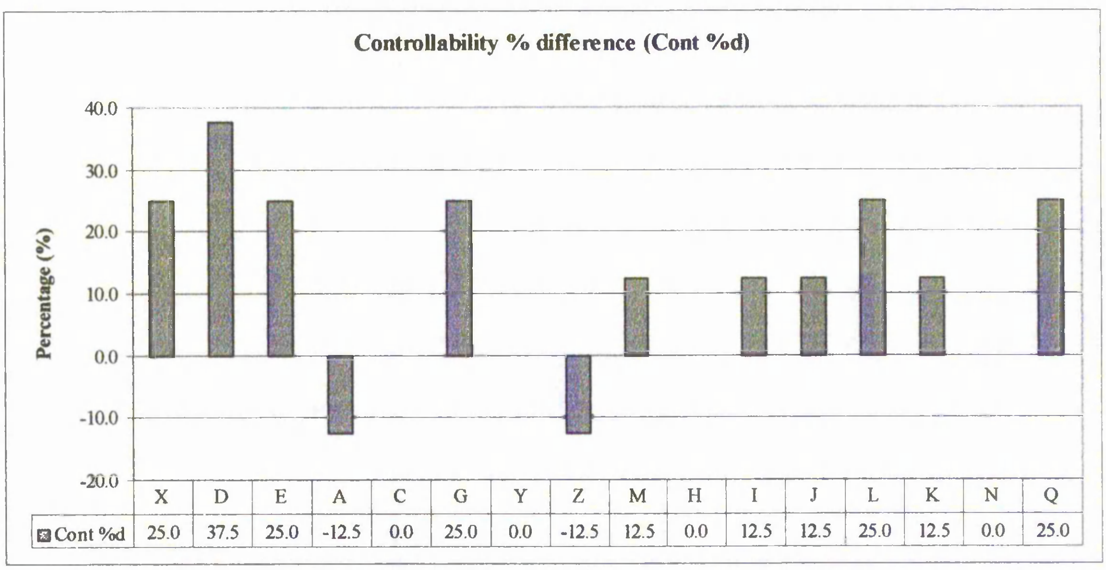


Chart 15. % difference in planned controllability of the VE input systems

Table 75. Summary of VR1 controllability results

No. of users	% effectiveness	Description
1	62.5	37.5 % less than planned controllability
2	75	25 % less than planned controllability
6	87.5	12.5 % less than planned controllability
4	100	Same as planned controllability

Table 76. Summary of controllability comparison

No. of users	% difference	Description
2	12.5	JM 12.5 % greater controllability than VR1
4	0	Controllability the same for both VE input systems
2	12.5	VR1 12.5 % greater controllability than JM
4	25	VR1 25 % greater controllability than JM
1	37.5	VR1 37.5 % greater controllability than JM
No. of users	**Description**	
2	Controllability of JM > VR1	
4	Controllability of JM = VR1	
7	Controllability of VR1 > JM	
System	**Lowest %**	**Highest %**
VR1	62.5	100
JM	37.5	100

Table 75 shows that 9 users scored less than planned controllability with VR1, with a lowest result of 62.5 %. Hence, future development requires refinement of VR1 to increase controllability. Table 76 details the controllability advantage that VR1 has over JM, with 7 users finding VR1 more controllable and only 2 users finding JM more controllable. It is also stated in Table 76 that the lowest controllability percentage for JM is 37.5, which is very poor.

Table 77. Controllability difficulties with each system

Joystick and mouse (JM)		
Measure	**No. users with difficulty**	**Difficulties**
Responsiveness	0	None
Non-interference	7 (X,D,E,C,G,Z,Q)	J button = 6; base J lift = 2 (X,E); M button actuation = 1 (D); played with J settings (X, Z)
Grip surface	0	None
Positioned easily	1 D	Reach too far, user in wheel chair = 1 (D)
Grasped easily	5 (X,D,Z,M,Q)	M = 2 (D,Q); J = 1 (Q); changeable grip J = 2 (X,Z); JM not comfortable = 1 (M); JM Too big = 1 (D)
Manipulated easily	7 (D,E,C,G,M,H,Q)	L/R turn J = 1 (D); M twist = 1 (E); alignment J = 5
Control location	3 (E,G,K)	Search for M button = 2, wrong M button = 1 (G)
Control actuation	1 (D)	Required tester to hold M still = 1 (D)
VR1		
Measure	**No. users with difficulty**	**Difficulties**
Responsiveness	0	None
Non-interference	7 (A,C,G,Z,M,H,Q)	Pitch = 7; base lifted = 1 (Q)
Grip surface	0	None
Positioned easily	1 (D)	Supported on wheelchair arms = 1 (D)
Grasped easily	2 (C,Z)	Not grip I properly = 1 (C); changes grip on I = 1 (Z)
Manipulated easily	3 (D,E,Z)	I manipulation could be easier = 3
Control location	0	None
Control actuation	0	None

Note: in Table 77 user labels are in brackets. Other notation, e.g. J, M or I is for the VE input systems.

The metrics of controllability were: responsiveness (feedback consistent and accurate); non-interference; grip surface (prevents unintended slipping); device positioned, grasped and manipulated easily and controls located and actuated easily. Table 77 lists the difficulties observed for each measure of controllability for each system.

Statistical analysis results

Using the Wilcoxon matched pairs signed-ranks test, the results of comparison of the controllability of VR1 and JM were found to be significant, with $P = 0.038$.

Discussion

VR1 and JM controllability

Responsiveness: the system is said to be responsive when any feedback, for example VE response to device movement, is consistent and accurate. Both systems were observed to have good responsiveness.

Grip surface: the grip surface was observed to be adequate for both VE input systems.

Positioned easily: so that User D could access all device functions within his reach envelope, VR1 had to be held in position by the test administrator, supported on the arms of his wheelchair. It was also difficult to position the JM system appropriately for this user. This system was placed as near to the user as possible so that he didn't have to reach too far for operation. Future development will require adaptation to the VE input system for wheelchair users.

VR1 controllability

Non-interference

Interference difficulties were observed to be one of the most significant controllability problems for both systems. 7 users were noted to experience interference difficulties with each system. For VR1, the look up/down function was the most frequent culprit, with all 7 users looking up or down accidentally. This difficulty could be avoided with the following refinement: 'the ability to turn look up/down on and off'. Alternatively, further research would be required to identify a more suitable approach for achieving look up/down. For one user, the base of VR1 lifted off the work surface when this pupil used excessive force for forward navigation. If VR1 could be fixed to the work surface, this interference could be avoided.

Two further interference difficulties, not noted in Table 77, were observed. User Q accidentally knocked the handlebars when using the cursor handle. He then had to reposition himself using the handlebars, so that he could access the interaction task again. This problem could be avoided with the following design suggestion: 'the navigation functions become active when a user grips the handlebars'. The other interference difficulty noted was that User Y veered slightly to the left when moving forward. This problem could be avoided if the device could be centred (quickly and easily) for each user.

Grasped easily

One user only gripped the top of the cursor handle on VR1, which caused a reduction in her control of this function. Another user kept changing his grip on the cursor handle, as though he was unable to achieve comfort. Further grip difficulties, not noted in Table 77, were observed with the handlebars and cursor handle:

- Handlebars: tight grip (1 user); finger grip rather than full grip (2 users); gripping just the ends of the handles (1 user); not gripping, but just pushing and pulling (1 user)
- Cursor handle: finger grip rather than a full grip (1 user)

All handles on VR1 require a power grip (see Chapter 7, Figure 28a), which all the users can achieve, hence future development would only require grip training.

Manipulated easily

It was observed that the cursor handle of VR1 needs to be easier to manipulate for Users D, E and Z. It was also noted that User E found the cursor handle particularly difficult to use for finer cursor positioning. Increased resistance to movement and reduced speed for positioning on smaller VE objects should increase ease of use of this particular function.

Locate and actuate interaction button easily

There are two interaction buttons on VR1, one for access with the left hand and the other for the right hand, but both give the same result. Both buttons were located and actuated successfully during the evaluation. The only exception to a seemingly perfect result was with User K, who accessed the button by bending his arm over the top of the device and approaching from the back.

JM controllability

Non-interference

The most common interference problem with the JM system was the joystick buttons. Some of the users would depress the front button accidentally when gripping the device, whilst for others the buttons were a distraction and something else to play with. Button interference sometimes resulted in looking up or down accidentally. However, interference, caused by the look up/down function was observed to be more frequent with VR1. The settings on the base of the joystick were also a distraction for 2 users. There are no extra functions to distract the user on VR1 as it was designed to satisfy the device attribute 'no excess functions accessible'. As with VR1, the problem of the base lifting up also occurred with the joystick, by 2 pupils whose use of this device was very energetic. For User D, actuating the mouse button interfered with his use of the VE system, as he required assistance to hold the mouse still, so that he could press the button. Finally (not noted in Table 77), User E lifted the mouse up, causing interference with use.

Grasped easily

Some users were observed to consistently change their grip on the joystick. As with the cursor handle on VR1, when a user only gripped the top of the joystick, control was reduced. Uncomfortable grips on both the joystick and mouse were observed for User M and Q, and for Users X and D, these devices were too large to grip with ease. Further alternative joystick grips, not noted in Table 77, were observed: a finger grip rather than a full grip and using two hands instead of just one.

Manipulated easily

The main manipulation problem with the JM system was recorded as 'using the joystick for alignment in the VE'. Two subjects who were using the joystick made frustrated comments: such as 'I can't see' and 'can't do it'. These comments indicated that the users found it difficult to complete the navigation task they were doing using the joystick. As the device attribute 'movement in VE same as user action' was incorporated into the VR1 prototype, it was hoped that this device would overcome navigation manipulation difficulties such as alignment. User E twisted the mouse to the left, which made task completion with this device much more complex. Additionally, this user found the mouse particularly difficult for finer cursor positioning.

Locate and actuate interaction button easily

The most obvious difficulty with mouse button access was with User D, who was not able to grip the device and actuate the button at the same time, hence, as previously stated, the test administrator had to steady the device for him. The positioning of the interaction buttons on VR1 enabled independent actuation for this user. It was also observed that 2 users would search for the mouse button, rather than interact automatically and that 1 user pressed the right mouse button instead of the left.

Conclusion

9 users scored less than planned controllability with VR1, with a lowest result of 62.5%. Hence, future development requires refinement of VR1 to increase controllability. Overall, VR1 was found to be more controllable than JM, as 7 users found VR1 more controllable in comparison to 2 who found JM more controllable. Table 79 (the controllability conclusion table) lists the controllability difficulties observed with each system and refinement required for improving the controllability of VR1. The results of the comparison of the controllability of VR1 and JM were found to be significant ($P = 0.038$).

9.3.8 Questionnaire 2 (Q2) – usability comparison of VR1 and JM

This questionnaire (see Appendix M) was completed with the user group, by interview, to obtain their opinion of which system is more usable. As with Q1, the questions were set at a level that the user group would understand, using symbols to depict the questions graphically, and the questions were based on the three indicators of usability: effectiveness, efficiency and satisfaction. The users were asked the following questions with reference to the two VE input systems:

1. Which do you like the best? (satisfaction)
2. Which is easier to use? (effectiveness)
3. Which is more tiring to use? (efficiency)
4. Which is more comfortable to use? (satisfaction)
5. Which is more fun to use? (satisfaction)

Table 79. Controllability conclusion table

<table>
<tr><th colspan="2">Device attributes met – VR1</th></tr>
<tr><td colspan="2">• Buttons – easy access, appropriate position
• Buttons – easy to actuate
• Modifiable operation difficulty (interaction guide plate; switch on/off secondary navigation)
• No excess functions accessible; is not distracting
• One user action = one VE function
• Can be repositioned</td></tr>
<tr><th colspan="2">Device attributes NOT met – VR1</th></tr>
<tr><td colspan="2">• Buttons – appropriate size (used most suitable buttons available at time of prototyping)
• Can be fixed to the work station
• Smooth operation, precise engineering (could be improved)
• Returns to centre position</td></tr>
<tr><th>Controllability difficulties – VR1</th><th>Refinement – VR1</th></tr>
<tr><td>Pitch control interfering with use</td><td>Ability to switch on/off; research alternative pitch control ideas</td></tr>
<tr><td>User accidentally knocked part-N when using part-I</td><td>Part-N fixed unless handlebars are gripped</td></tr>
<tr><td>User veered to left slightly when moving forward</td><td>Centre positioning adjustment control</td></tr>
<tr><td>Not gripping part-I or part-N correctly</td><td>Training to grip device correctly</td></tr>
<tr><td>Part-I quite difficult to manipulate
Part-I difficult for finer cursor positioning</td><td>Increase the resistance to movement of the cursor function; incorporate 2 cursor speeds – one fast and one slow</td></tr>
<tr><td>User accessed interaction button indirectly</td><td>Training to access button directly</td></tr>
<tr><td>Device had to be supported on user's wheelchair arms</td><td>Adaptation for wheelchair users</td></tr>
<tr><td>Base Lifted off work surface with forceful use</td><td>Device can be fixed to the work surface</td></tr>
<tr><th colspan="2">Controllability difficulties – JM</th></tr>
<tr><td colspan="2">• Joystick buttons interfered with use, i.e. accidental pitch
• Settings on base of joystick caused distraction
• Base of joystick lifted up with energetic use
• Mouse lifted up
• Changeable grip on joystick
• Gripping joystick incorrectly, i.e. just grip top, finger grip and two handed grip
• Joystick manipulation difficulties, i.e. for alignment tasks
• Difficult to use mouse for finer cursor positioning
• User not able to independently actuate mouse button
• Not automatically find mouse button, search required</td></tr>
</table>

Results (Q2)

The full answers to Q2 are detailed in Appendix M. Table 80 lists the totals of the answers in favour of each system. These totals indicate which system the users found more usable and are depicted on Chart 16.

Q2 was not completed with User C, as she was unavailable due to sickness. The 0.5 and 4.5 results were given as User M answered 'same' for 'more comfortable' (question 4) and 0.5 was scored for each system. Column 4 in Table 80 indicates whether the tester thought the user understood the questions or not. Confidence in the accuracy of the users' answers is quite low, as the tester could only be certain that 7 users gave their intended answers.

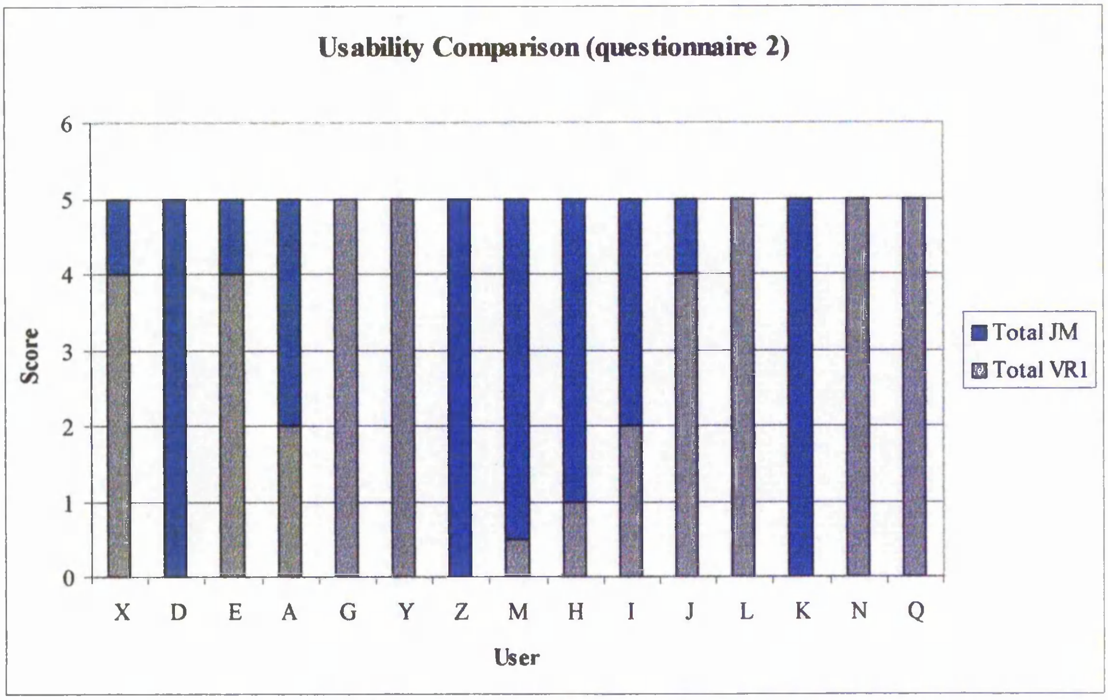


Chart 16. User group comparison of usability of the VE input systems (questionnaire 2)

Table 80. Totals of answers in favour of each system

User	T-VR1	T-JM	Understood?	More usable
X	4	1	Not vary	VR1
D	0	5	Yes	JM
E	4	1	Not sure	VR1
A	2	3	Most	JM
C	-	-	-	-
G	5	0	Yes	VR1
Y	5	0	Yes	VR1
Z	0	5	Yes	JM
M	0.5	4.5	Think so	JM
H	1	4	Not sure	JM
K	0	5	Think so	JM
N	5	0	Yes	VR1
Q	5	0	Yes	VR1

Baring the uncertainty of the results in mind, Table 80 shows that 6 users found VR1 more usable and the same number of users found JM more usable. Hence no system is clearly more usable, in the users' opinion, than the other. Table 81 lists the results for each question. These results identify which system the users liked best and which they thought was easier, more tiring, more comfortable and more fun to use.

Table 81. Results of individual questions

Question	T-VR1	T-JM	Result
Like best	7	5	VR1
Easier to use	5	7	JM
More tiring	6	6	Same
More comfortable	6	5	VR1
More fun	7	5	VR1

Table 81 shows that for like best (q1), more comfortable (q4) and more fun (q5), VR1 did slightly better. As these three questions are all related to the usability attribute of satisfaction, it could be concluded that VR1 produces slightly more user satisfaction than JM.

For easier to use (q2), JM was the favourite VE input system, by a margin, and for more tiring (q3), both systems gained the same number of votes. These results suggest that future development of VR1 requires refinement to increase ease of use and to make the device less tiring to use.

Conclusion

Baring in mind the uncertainty of the accuracy of user answers, the same number of users found each system more usable, hence no system is clearly more usable, in the users' opinion, than the other. VR1 was marginally favoured for like best, more comfortable and more fun, hence this device produced slightly more user satisfaction. Finally, future development of VR1 requires refinement to increase ease of use and to make the device less tiring to use.

9.4 FURTHER DEVICE ATTRIBUTES MET OR NOT MET

The following requirement categories from the design specification have already been covered by the usability attribute evaluation: product appearance, ergonomic design, interface and functional assistance, cognitive factors and physical factors. Table 82 the device attributes met or NOT met (by VR1) for the following categories of the design specification: construction and computer input. The support and workstation device attributes (from the design specification) were not employed in the VR1 prototype, due to time restrictions, and hence have not been covered in Table 82.

Table 82. Construction and computer input device attributes

Construction requirements met
• Strong and flexible casing • Accurate part mouldings • Reliable electronic design, minimal parts • Durable materials • Non hazardous materials
Construction requirements NOT met
• Parts fit together precisely • Wipe proof joints, sealed • Robust mechanical design, minimal parts • Prototypes carefully manufactured • Use cost effective materials and manufacture
Computer input requirements met
• Compatible with VE software • Navigation – could mimic joystick input to PC • Interaction – could mimic mouse input to PC • Compatible with a PC • Controls 3D navigation and 2D interaction
Computer input requirements NOT met
• Compatible with WWW VEs

Conclusion

VR1 meets most of the computer-input device attributes. However, the current VR1 prototype requires additional software to be loaded into the VE before the device is recognised. Future development should involve increasing computer-input compatibility, so that the extra software is not required. In order to meet more of the construction device attributes, suitable manufacturing and adequate financial backing will be required.

10. Summary, conclusions and future development

10. 1 SUMMARY

The purpose of this research was to examine the control of virtual environment (VE) navigation and interaction tasks for people with moderate to severe learning difficulties. Initial research concluded that is was important to consider the user abilities, the tasks and the working environment, in order to select or develop usable VE input devices. Consequently, a multi-disciplinary design methodology was carried out, which involved an analysis of the users, the tasks and the working environment. The second step of this methodology resulted in the development of a design specification, which was based on the analysis data, and listed the required device attributes for the selection or design of usable VE input devices. A technology review was conducted to identify any existing computer input devices that met the device attributes in the design specification or could be adapted to meet the requirements. As this review presented no satisfactory solutions, it was necessary to proceed to the next step of the methodology 'concept and prototype design', through which, a new VE input system (VR1) was developed. This prototype was then tested with a user group of 16 young people with moderate to severe learning difficulties (the 'user-based assessment' step of the employed methodology).

To recap, the objectives of the user-based assessment were as follows:

- Evaluate the usability of VR1
- Compare the usability of VR1 and JM (*note: the JM system includes the joystick and mouse, which are commonly used by people with learning difficulties for VE control)*
- Identify whether VR1 meets the device attributes listed in the design specification
- Identify any usability difficulties with VR1 and suggest refinement
- Test the following hypothesis:

  - The employment of the multi-disciplinary design methodology results in the design and development of a VE input system for young people with moderate to severe learning disabilities, which has greater usability than a commonly used system for this user population.

There were two main result sections in the previous chapter: the usability analysis of VR1 and the comparison of the usability of VR1 and JM system. Firstly, this chapter will outline the main results and conclusions from these result sections, which will cover the following evaluation objectives: evaluate the usability of VR1; compare the usability of VR1 and JM and test the hypothesis. The conclusions that relate to the device attributes met or NOT met by VR1, usability difficulties and future prototype refinement will then be presented to satisfy the remaining evaluation objectives.

Required descriptions

Each VE input system was assessed for overall usability and the following usability attributes: compatibility, efficiency, effectiveness, satisfaction, biomechanical load and controllability. A planned case was defined for the metrics of each usability attribute (see Chapter 9: 9.1.2 Planned usability). The percentage of planned usability (% PU) is the calculated percentage of the planned case for usability. A percentage of each planned usability attribute was also calculated (i.e. % P-effectiveness).

10. 2 USER-BASED ASSESSMENT (UBA) – MAIN RESULTS/CONCLUSIONS

10.2.1 Usability analysis of VR1

This section, on the usability of VR1, will cover the main results/conclusions for overall usability, obviousness (usability attribute) and questionnaire 1 (Q1).

Overall usability (VR1)

Measures: obviousness; compatibility; efficiency; effectiveness; satisfaction; controllability and biomechanical load (the usability attributes).

Conclusions:

- The lowest percentage of planned usability (% PU) was calculated as 81.8%. Hence, it can be concluded that all 16 users who tested VR1 found it quite usable.
- As 9 pupils scored less than 100% usability, there is room for improvement in the usability of VR1 for some users.

Obviousness

Metrics: initial test (functions subject could use without training); training required and learning time (number of sessions before user became competent).

Conclusions:

- 14 of the users achieved >= 88.9% of planned obviousness. This shows that the majority of the user group found the functions of VR1 quite obvious.
- 10 users achieved >= planned obviousness. Hence, 10 out of the 16 users who tested VR1 found its operation very obvious.
- The users who scored lower for obviousness required further instruction, after the planned demonstration. For these users, the obviousness of VR1 could be improved by meeting the following device attributes: 'form indicates function' and 'colour and symbol cues to function' (for forward, backward, side-step, look up/down and the cursor handle).

Q1 (usability of VR1)

This questionnaire was completed with the user group to gain their perspective on the usability of VR1. The questions were based on the three main indicators of usability: effectiveness, efficiency and satisfaction (ISO 9241-9 European Standard). Confidence in the accuracy of the users' answers was quite low, as the test administrator could only be certain that 7 pupils gave their intended answers. Baring this in mind, the results of Q1 suggest that VR1 should be made less tiring, more comfortable and easier to use.

10.2.2 Comparison of usability of VR1 and JM

This section will present the main results/conclusions for the comparison of the usability of both VE input systems and the following usability attributes: compatibility; efficiency; effectiveness; satisfaction; biomechanical load and controllability. The results are based on the 13 pupils who tested both VE input systems. The JM system could not be assessed for obviousness, as all members of the user group had previous experience with the joystick and mouse. The conclusions from questionnaire 2 (Q2) will also be presented in this section.

Overall usability

Metrics: compatibility; efficiency; effectiveness; satisfaction; controllability and biomechanical load.

Conclusions:

- The results of the % PU for VR1 were greater than JM for the majority of the subjects tested, by 1.8 to 15.8%. This indicates that VR1 is more usable than JM for the majority of the user group.
- The results of the comparison of the usability of VR1 and JM were found to be highly significant (P = 0.008).

The performance results of the attributes of usability were examined to identify more specific details on how VR1 had greater usability than JM.

Compatibility

Metrics: anthropometric and biomechanical difficulties.

Conclusions:

- VR1 was found to be 100% compatible for all users tested, whereas, 4 users experienced compatibility difficulties with JM. Hence, VR1 was found to be more compatible for the user group than JM.
- The results of the comparison of the compatibility of VR1 and JM were not found to be significant (P = 0.068).

Efficiency

Metrics: task time (time to complete all tasks); harshness (harsh use of a device) and effort displayed in use.

Conclusions:

- As the lowest % P-efficiency for VR1 and JM was calculated as 77.8%, both systems were found to be quite efficient. However, improvement is required with the efficiency measures of effort and task time for both systems.
- 5 pupils found VR1 more efficient than JM, whereas, 3 pupils found JM more efficient than VR1. Hence VR1 was found to have a marginal efficiency advantage over JM.

- The results of the comparison of the efficiency of VR1 and JM were not found to be significant (P = 0.363).

Effectiveness

Metrics: unproductive device and task actions; disorientation; verbal and physical support; task completion (%) and use after training.

Conclusions:

- 8 pupils scored >= planned effectiveness with VR1, hence VR1 was found to be effective for the majority of the user group.
- As 5 pupils achieved lower than planned effectiveness with VR1, with a lowest score of 76.9%, there is room for improvement in the effectiveness of this device. Future refinement of VR1 should focus on reducing the unproductive device actions and disorientation, which caused the most difficulty.
- 8 pupils found VR1 more efficient than JM, whereas, 5 pupils found JM more efficient than VR1. Hence, VR1 was found to have a marginal effectiveness advantage over JM.
- The results of the comparison of the efficiency of VR1 and JM were not found to be significant (P = 0.675).

Satisfaction

Metrics: comfort (did the user look uncomfortable, comfortable or very comfortable) and user attitude (was the user discontent, content or happy).

Conclusions

- Only 1 user achieved less than 100% satisfaction with VR1. This user experienced discomfort with VR1, as the device had to be supported on his wheelchair arms. Hence, the only refinement required to improve user satisfaction with VR1 is to ensure the device is fully accessible for wheelchair users.
- 8 pupils found VR1 more satisfactory than JM, whereas, only 1 pupil found JM more satisfactory than VR1. The majority of users were observed to have a more positive attitude when using VR1 than when using the JM system and more users found the JM system uncomfortable than VR1. Hence, VR1 was observed to be more satisfactory than JM.
- The results of the comparison of the satisfaction of VR1 and JM were found to be significant (P = 0.021).

Biomechanical load

Metrics: neutral posture deviation

Conclusions

- No harmful deviation was observed with either VE input system.

Controllability

Metrics: responsiveness (feedback consistent and accurate); non-interference; grip surface (prevents unintended slipping); device positioned, grasped and manipulated easily and controls located and actuated easily.

Conclusions:

- 4 users achieved planned controllability with VR1; hence this device has good controllability for some users.
- 9 users scored less than planned controllability with VR1, with a lowest result of 62.5%. Hence, future development requires refinement of VR1 to increase controllability for many users.
- Overall, VR1 was found to be more controllable than JM, as 7 users found VR1 more controllable in comparison to 2 who found JM more controllable.
- The results of the comparison of the controllability of VR1 and JM were found to be significant (P = 0.038).

Q2 (comparison of usability of VR1 and JM)

This questionnaire was completed with the user group to obtain their opinion of which system is more usable. As with Q1, the questions were based on the three main indicators of usability: effectiveness, efficiency and satisfaction. Confidence in the accuracy of the users' answers was quite low, as the test administrator could only be certain that 7 pupils gave their intended answers.

Conclusions:

- The same number of users found each system more usable, hence no system is clearly more usable, in the users opinion, than the other.

- VR1 was marginally favoured for like best, more comfortable and more fun. As these three questions are all related to the usability attribute of satisfaction, it could be concluded that VR1 produced slightly more user satisfaction than JM.
- Future development of VR1 requires refinement to increase ease of use and to make the device less tiring to use.

10.3 TEST OF HYPOTHESIS

The results for VR1 for the comparison of overall usability and the individual attributes of usability (excluding biomechanical load) all showed that VR1 scored greater than JM. The most significant result was for overall usability, as the majority of users were observed to find VR1 more usable than JM, with $P = 0.008$. Further significant results were found for satisfaction and controllability, with VR1 having a significant advantage over JM. For efficiency and effectiveness, the results were only slightly better for VR1 and hence were not found to be significant.

A subsequent section (10.6) entitled 'device attributes' will point out that some of the attributes from the design specification were not met by the VR1 prototype. It is expected that, if all the device attributes from the design specification are employed in a future prototype, the efficiency and effectiveness and hence overall usability of VR1 will improve. Hence, as VR1 was found to be significantly more usable than JM, even though all the device attributes from the design specification have not been met, it can be concluded that the following hypothesis is supported:

- The employment of the multi-disciplinary design methodology results in the design and development of a VE input system for young people with moderate to severe learning disabilities, which has greater usability than a commonly used system for this user population.

10.4 DISCUSSION OF UBA MAIN RESULTS/CONCLUSIONS

Usability analysis

It has been concluded that the proposed hypothesis is supported as the results showed that the majority of users were observed to find VR1 more usable than the JM system. This result was found to be highly significant, with $P = 0.008$. However, the weight behind this conclusion is dependent on the strength of the usability analysis method that was applied. There are several strengths to this method. Firstly, it follows the usability engineering process that is detailed in the HCI literature by Faulkner (1998). Secondly, the usability attributes, for evaluating the usability of the VE input systems, are the 'guiding principles' for the requirements of non-keyboard input devices (European Standard ISO 9241-9: section 4). Thirdly, the chosen method, including the usability attributes, metrics and rating scale employed for the Wilcoxon statistical analysis, was agreed upon by the usability team (see Chapter 4: 4.4.2 Multi-disciplinary design methodology).

It could be argued that the rating scale employed is a weakness in the usability analysis method, due to its subjective nature. However, this rating scale followed the specification of the Wilcoxon statistical analysis (Greene and d'Oliveira, 1990) and as it was consistent for both VE input systems, it can be concluded that the comparison of usability of these systems is valid. Alternatively, a Sign test (Greene and d'Oliveira, 1990) could have been employed to compare the usability of VR1 and the JM system. This would involve the calculation of the number of pupils obtaining and not obtaining the planned case for usability and the usability attributes. The benefit of this method is that it is less subjective, as the rating scale employed for the Wilcoxon is not required. However, the Wilcoxon extracts more information from the data than the Sign test because it analyses information not only about the *direction* of scores but also about the relevant *sizes* of the differences in scores. The Wilcoxon is therefore the usual test for two related conditions (Greene and d'Oliveira, 1990).

Obviousness

The results were very positive for VR1 for the usability attribute obviousness, with 10 pupils either achieving or surpassing the planned case for this attribute. The JM system could not be assessed for obviousness, as all members of the user group had previous experience with the joystick and mouse. To account for this previous experience with the JM system, the pupils were given 1 session with this system and at least 3 sessions with VR1. Additionally, for the majority of the usability metrics, the data from the final session with VR1 was considered the most significant. As previously stated, the obviousness of VR1 could be improved by meeting the following device attributes: 'form indicates function' and 'colour and symbol cues to function' (for forward, backward, side-step, look up/down and the cursor handle).

Compatibility

All of the pupils achieved planned compatibility with VR1, whereas 4 pupils experienced compatibility difficulties with the JM system. This finding is supportive of the user analysis that was employed in the first step of the multi-disciplinary design methodology. The user analysis identified the physical attributes of the user group and consequently VR1 was designed to meet the requirements of these physical attributes. Hence, this new device was developed to avoid the anthropometric difficulties observed by 4 pupils using the JM system.

Efficiency

The metrics that were used for assessing the efficiency of each VE input system were effort, harshness and task time. Notable effort was recorded for some pupils using the cursor control handle. When this function was set at its slowest speed the effort observed was reduced. This introduces an interesting discussion concerning the speed of interaction using the cursor control handle (part-I) versus the mouse. The advantage of the mouse is that it was observed to be a quicker interaction method than part-I for the pupils who were able to control both devices. The advantage of part-I is that all pupils displayed control of this function, whereas the mouse proposed control difficulties, including random movement (user B), button actuation (user D) and fine cursor positioning (user E). Hence, these findings suggest that there may not be one solution for interaction control for young people with learning difficulties and that future research should aim to develop a VE interaction method that is both controllable and efficient in terms of interaction speed.

Effectiveness

The results showed that there is room for improvement in the effectiveness of both VE input systems. The unproductive device actions that were noted for VR1 included trying to use part-I for navigation tasks and the look up/down function for moving forward. It is possible that part-I was mistaken for navigation control due to its similarity to a joystick (which is commonly used for navigation). This finding suggests that it would be more effective to develop a VE interaction method that does not share the same conceptual model as a learned navigation method. VR1 was designed to meet the device attribute 'once user action = one VE function', to increase accessibility to the secondary navigation movements of look up/down and side-step. Achieving these movements requires 2 user actions with the joystick, e.g. for look up, the user has to press a joystick button *and* pull the joystick backwards. The accessibility to the secondary navigation movements was observed to be positive using VR1. However, as the pupils were not specifically shown how to achieve these movements (during the user-based assessment) using the joystick, a conclusion cannot be made as to which navigation method provides the greatest accessibility. It is expected that requiring 1 user action versus 2 would impose less cognitive load on the user and hence provide greater access for people with moderate to severe learning difficulties. This is a further investigation for future research.

Satisfaction

The metrics for the usability attribute satisfaction were comfort (did the user look uncomfortable, comfortable or very comfortable) and user attitude (did the user look discontent, content or happy). Hence, the results for this usability attribute are very subjective. Baring this in mind, VR1 was observed to rate better than JM for satisfaction and this result was found to be significant ($P = 0.021$). Greater discomfort was observed with the JM system than with VR1 and the comparison of the results for the usability attributes showed that the discomfort with JM was related to the compatibility difficulties recorded for this system. The majority of users were observed to have a more positive attitude when using VR1 than when using the JM system. It is possible that this result could be partly due to the VR1 prototype being 'new and exciting'. However, previous research suggests that these factors (new and exciting) may positively effect device use, as it has been stated that success in learning to use communication devices has also been associated with attitude ratings, such as drive and attitude toward technology (Goodenough-Trepagnier and Felts, 1986). Additionally, Cress and French (1994) report that low motivation to learn a device, however easy it may appear in isolation, is likely to increase the effective difficulty in acquiring adequate device skills.

Controllability

Overall, VR1 was found to be significantly more controllable than JM, with $P = 0.038$. Interference difficulties were observed to be one of the most significant controllability problems for both systems. The main interference difficulty with VR1 was due to the pitch control (look up/down), as 7 users were observed to pitch accidentally, which resulted in disorientation for some pupils. However, the 9 pupils that used VR1 with the virtual supermarket displayed intelligent control with the pitch function, which indicates that this concept has potential. Hence, there are several paths for future development:

- Refine the current pitch concept so that interference is eliminated
- Develop a training method that eliminates the pitch interference. For example, the secondary navigation functions are only introduced when a user displays competency with the primary navigation function.
- Design and develop an alternative concept for controlling look up/down in the VE

Many pupils were observed to experience difficulty in using the joystick to complete the more awkward navigation tasks, e.g. aligning their position in front of the clothes cupboard in the virtual factory (see Chapter 8: 8.4.3 Tasks). This manipulation difficulty was not observed with VR1. The device attribute 'movement in VE same as user action' was incorporated into VR1 with the aim to achieve natural navigation that would be less cognitively taxing on the user. The observation that alignment tasks were easier to achieve with VR1 suggests that the aim of this device attribute was met. This discussion supports the multi-disciplinary design methodology as the aforementioned device attribute was employed on the basis of the cognitive attributes of the user group.

VE input system usability and physical/cognitive difficulty

The main physical difficulty observed with VR1 was that user D was unable to reach the input device when it was on the work station due to being in a special chair (see 9.3.7 Controllability – positioned easily). However, the same problem was experienced with the JM system. As previously stated, the solution for either VE input system would be to design an adaptation for special chair users. In conclusion, VR1 was found to be appropriate for the physical ability of the user group.

In general, the individuals from the user group with a lesser learning difficulty (moderate to severe as opposed to severe) were able to use both VE input systems well. In this case VR1 might be the preferred system as it is an integrated unit and may be more enjoyable to use. For users with a greater learning difficulty (severe as opposed to moderate to severe) VR1 was observed to be the more usable VE input system. For example, user E displayed random control with both the joystick and mouse in comparison to quite effective control of the navigation and interaction functions of VR1 (see 9.4.3 JM effectiveness – unproductive task actions). In conclusion, observation indicated that VR1 is particularly an improvement on the JM system for individuals with a more severe learning difficulty.

10.5 REVIEW OF RESEARCH PROCESS

This section covers improvements or strategies that could be employed to strengthen the research process that has been employed in this project. Firstly, step 4 of the multi-disciplinary design methodology, produce concept designs and prototypes, was undertaken by the author, who is an industrial designer. This step would be strengthened by the involvement of a team of designers that could bring a wider range of concept ideas and engineering skills to the product development. If a design team were involved, the 'concept selection matrix' method (see

Chapter 7: 7.2.8) would be strengthened as the decisions made about the suitability of each concept would be a team effort. Continuing on the design stage of the methodology, the results of the device test (see Chapter 7: 7.2.7) showed that for 2 of the 5 pupils that tested the devices (roller ball and joystick), the roller ball was observed to be the most suitable interaction method. These 2 pupils (users G and H) were able to use both devices, but their interaction with the joystick was slower. Whereas, for 2 different pupils (users D and E) the joystick was observed to be the most suitable, as the following difficulties were observed with the roller ball: knocked ball accidentally and random movement. Hence, it was concluded that the input method would need to be adaptable for different users. This research suggests that future development should consider developing alternative interaction methods that could be evaluated in parallel to each other.

The results obtained for the percentage of planned usability could be improved. In the current method the totals for each usability attribute are not equal, e.g. planned (100%) compatibility = 9, whereas, planned (100%) effectiveness = 26 (see Chapter 9: Table 45. Planned usability). In order to resolve this unbalance of totals, further calculation would be required to ensure each usability attribute has equal weighting on the resulting overall usability percentage. The following is an example of how this would be achieved:

Note: this calculation would be for the comparison of overall usability, hence, obviousness has not been included.

1. Divide 100% usability by the number of usability attributes (UAs): $100 \div 6 = 16.7$
2. Divide the result of step 1 by the planned total for the UA: $16.7 \div 26$ (effectiveness) $= 0.6$
3. Multiply the user's total for the UA by the result of step 2 (0.6): $20 \times 0.6 = 12$

For the above example, 12% is the result for effectiveness for this user. This 12% would then be added to the percentages for the other 5 usability attributes to obtain a more balanced overall usability percentage. However, as the method employed for the usability analysis was consistent for both VE input systems, the results for the comparison of usability are still valid.

As stated in the discussion on the usability attribute satisfaction, the results for this attribute are very subjective, due to the nature of the metrics that were employed for its assessment. Hence, there is room for improvement in the analysis of this usability attribute. One approach would be to research a method of obtaining the required measures of satisfaction from the users. An attempt was made to achieve this using questionnaire 2 (see Chapter 9: 9.3.8), which asked the users to choose the VE input system that they liked the best, was more comfortable and was more fun. This leads onto a discussion on the use of questionnaires with people with learning difficulties. The author attempted to set the questions at a level that the user group would understand and used symbols to depict the questions graphically. However, the confidence in the accuracy of the users' answers was quite low, as the test administrator could not be certain that all of the pupils gave their intended answers. Further research is required to investigate the possibility of developing a valid questionnaire for the assessment of the interface, including user satisfaction, for people with learning difficulties. For this research the SUMI (Software Usability Measurement Inventory) and QUIS (Questionnaire for User Interface Satisfaction) (Schneiderman, 1992) would be useful references. On a related line of research, it would also be valuable to investigate the development of a standard format for conducting an evaluation with people with learning difficulties. The basis for this research is as follows: due to the cognitive ability and diverse range of communicative ability of the UE (Usability Evaluation) user group, it was difficult to adhere to a standard evaluation procedure in terms of instruction and direction given to the subjects (see Chapter 8: 8.4.4 Session procedure).

10.6 DEVICE ATTRIBUTES

One of the objectives of the user-based assessment was to identify whether VR1 met the device attributes listed in the design specification. This objective was partly satisfied by the conclusion tables that were listed for the following usability attributes: 'obviousness'; 'compatibility'; 'satisfaction' and 'controllability'. The conclusion tables can be found in Chapter 9. The construction and computer-input device attributes (from the design specification) were discussed separately in the final section of Chapter 9: further device attributes 'met' or 'NOT met'.

Obviousness

- Many of the device attributes that help to increase the obviousness of the VE input system have been met by VR1.
- The main attributes that have not been met by VR1 are: 'form indicates function & colour' and 'symbol cues to function' (for forward, back, side-step, pitch and cursor control).
- Future development might involve experimenting with the feedback device attributes, e.g. 'lights up', 'makes noise' or 'haptic sensation with user action', in order to identify whether additional feedback increases device obviousness.

Compatibility

- For compatibility, 9 device attributes have been met by VR1, whereas only 4 have not been met.
- Future development, to increase the compatibility of VR1, will include: 'ensuring the device can be operated with just one hand'; 'ergonomic muscle support for using interaction functions' and 'making the device more lightweight and robust'.

Satisfaction

- For satisfaction, 4 device attributes were met, whereas only 2 were not met.
- The following device attributes could increase user satisfaction: 'comfortable to carry for adult or older student' and 'visual, auditory and haptic feedback'.

Controllability

- Out of the 10 device attributes that were employed to increase the controllability of VR1, 4 were not met.
- Meeting these device attributes could further increase compatibility of VR1: buttons – appropriate size; can be fixed to workstation; smooth operation/action and returns to centre position.

Construction and computer-input

- In order to meet more of the construction attributes, suitable manufacturing and adequate financial backing will be required.
- VR1 meets most of the computer-input attributes.
- The VR1 prototype requires additional software to be loaded into the VE before the device is recognised. Future development should involve eliminating this additional software to increase computer-input compatibility.

10.7 USABILITY DIFFICULTIES AND DESIGN REFINEMENT

The remaining evaluation objective that has not been discussed is: identify any usability difficulties with VR1 and suggest refinement. Usability difficulties were identified for both VE input systems. These difficulties are listed in the conclusion tables (see Chapter 9). These conclusion tables also detail the design refinement required to overcome the difficulties identified with VR1 and consequently improve the overall usability of this device.

10.8 RESEARCH FINDINGS IN RELATION TO RESEARCH FIELD

Firstly, the research undertaken has built on the foundational study of Brown et al (1997), which compared a series of computer input devices for use by people with learning difficulties to control VE tasks. This research project has added to the study by Brown et al by identifying the specific usability difficulties that young people with learning difficulties experience in using the joystick and mouse (commonly used devices) to control navigation and interaction tasks respectively (see Chapter 3: Input Device Evaluation).

Secondly, this research has resulted in the production of the first VE input system for people with learning difficulties that provides control of both VE navigation and interaction tasks. Whereas, previously developed VE input device solutions for this user population, Mojo and the Tangible Interface (see Chapter 2: 2.3.3 Solutions), have provided VE navigation or interaction control, but not both.

The employment of the multi-disciplinary design methodology and research finding that this methodology resulted in the production of a VE input system, which has greater usability than a commonly used system (joystick and mouse) could contribute greatly to the wider research field of VE applications for disability. For example, the multi-disciplinary methodology could be employed by researchers investigating the use of VEs for TBI patients (Davies et al, 1999) or for people with Asperger's Syndrome (Parsons et al, 2000), to enable the selection or development of an appropriate VE input system for the relevant user population. If the methodology is employed for many disability applications the knowledge of usable VE control devices for various disabilities and the range of new computer access methods would increase. A database of VE input methods for people with disabilities could then be developed and this valuable knowledge shared by the various disability fields. This database concept relates to the optimal VE access solution stated by Brown et al (1997): the optimal solution would be to recommend a series of navigation and interaction devices that would allow people with a range of cognitive and motor skills abilities to access VEs with ease and control.

Furthermore, the research undertaken is contemporary as it reflects the focus of research for Framework 6 (European call for research): 1.2.4 Knowledge and interface technologies, the launch of which coincides with the completion of this research study. Section 1.2.4 is detailed as follows:

> 'Research will focus on interfaces and interactive surfaces that are natural, adaptive and multi-sensoral, for an ambient landscape that is aware of our presence, personality and needs, and which is capable of responding intelligently to speech, gesture or other senses. The aim is to hide the complexity of technology by supporting a seamless interaction between humans and devices, virtual and physical objects and the knowledge embedded in everyday environments. This includes research on virtual and augmented reality'. (Framework 6, 2002).

Prediction of usability of VR1 for other user groups / applications

In section 4.3.2 it is stated that the 'design for all' strategy indicates that the design of a VE input devices for users with learning difficulties will result in the development of an input device that is easier to use for people who are not cognitively impaired. Hence, as the result of the user-based assessment indicate that VR1 is more usable than JM for the majority of the user group (see 10.2.2 *Overall usability*), it can be predicated that users without a learning difficulty will also find VR1 more usable than JM.

Although VR1 has been specifically designed for controlling VEs (which include interactive 3D games), the navigation functions of this device are also relevant to powered wheelchair control. Currently VR1 is interfaced with the game and mouse port of a personal computer. Hence, further interface development may be required to facilitate the use of this device for powered wheelchair navigation.

10.9 FUTURE DEVELOPMENT

10.9.1 Continue the multi-disciplinary design process

The next stage in the multi-disciplinary design methodology is stated as 'incorporate user-derived feedback into the design process'. Hence, the first step would require the modification of the design specification, to include the design refinement (see Chapter 9: conclusion tables), which has been identified through the user-based assessment. Any research (e.g. contextual information, ergonomics and standard conformity), that is required to employ the necessary refinement, would also be conducted. The iterative process of evaluate-refine-evaluate would continue, until the VE input system is found to sufficiently satisfy the usability metrics.

10.9.2 EPSRC continued research

An EPSRC research grant has been awarded based on this research, to continue to explore the design and development of VE input devices for people with learning difficulties (Standen et al, 2002; Appendix A). However, this new research requires that the input device is usable for adults as well as younger people with learning difficulties. Hence, additional research will be required for step 1 of the multi-disciplinary design methodology 'understand and specify the context of use'. This will involve an analysis of the following:

- The cognitive, physical and perceptual abilities of the user population (adults with learning difficulties)
- The VE tasks that the user population will perform
- The environment in which the user population will use the VE system

Any new design requirements identified from this contextual data will be added to the design specification for future prototype design and development.

The VR1 prototype has been designed for the end-users, who are the primary stakeholders (see Chapter 5: 5.3 User Analysis). The other relevant stakeholder groups include: educators; parents or carers; therapists and technical maintenance staff. The User Analysis tool from the USERfit methodology (Poulson et al, 1996) requires that the attributes of the stakeholders are researched and design requirements specified based on these attributes. An extension to the EPSRC research project would be to identify the design requirements of the aforementioned stakeholder groups.

10. 9.3 Further lines of research

The research study undertaken has pointed to several areas of investigation for future research. A selection of these areas are described in this section and the remaining are listed in table 83.

Table 83. Further lines of research

• Research the development of a VE interaction method that is both controllable and efficient in terms of interaction speed (see discussion on efficiency).
• Investigate whether 1 user action versus 2 for achieving the secondary VE navigation movements would impose less cognitive load on the user and hence provide greater access to these movements for people with moderate to severe learning difficulties (see discussion on effectiveness).
• Research paths for future development of the pitch function on VR1 (see discussion on controllability): - Refine the current pitch concept so that interference is eliminated. - Develop a training method that eliminates the pitch interference. For example, the secondary navigation functions are only introduced when a user displays competency with the primary navigation function. - Design and develop an alternative concept for controlling look up/down in the VE.
• Consider developing alternative VE interaction methods that could be evaluated in parallel to each other.
• Investigate the possibility of developing a valid questionnaire for the assessment of the interface, including user satisfaction, for people with learning difficulties.
• Investigate the development of a standard format for conducting an evaluation with people with learning difficulties.
• Investigate the employment of the multi-disciplinary design methodology for the selection or development of usable computer access devices for other user populations, e.g. people with Asperger's Syndrome.
• Research whether the navigation functions of VR1 are appropriate for powered wheelchair navigation.

Navigation and Interaction

A device attribute from the cognitive factors section in the design specification is 'navigation and interaction functions in one device'. The benefits of this attribute are expected to be: *increased transparency* – as the user is not required to switch between devices; *increased focus on the VE* – as all functions will be centrally located on one device and *compact design* – a more integrated system. 'Increased transparency' and 'increased focus on the VE' were not measured during the evaluation sessions. Hence, future research could consider the following:

- The identification of a set of measurement criteria to identify whether a VE input system is more usable when the navigation and interaction functions are combined in one input device.
- The development of a specific VE, which can be used to evaluate whether a VE input system is more usable when the navigation and interaction functions are combined in one input device.

Secondary navigation functions required?

During the user-based assessment of VR1 and the JM system, it was observed that the look up/down function of VR1 interfered with device use (see Chapter 9: VR1 controllability, non-interference). It was also observed that the secondary navigation functions of look up/down and side-step were utilised infrequently. Hence, a future line of research would be to investigate whether these secondary navigation functions are necessary for VE control for people with learning difficulties.

Extended training or new device development

Cress and French (1994) have reported on a study that compared the performance of three subject groups, including children with learning difficulties, on their use of the following computer input devices: touch-screen; mouse; keyboard; trackball and locking trackball. They suggest that the unsuccessful children with learning difficulties might acquire device mastery skills with more extended training and/or development of further cognitive and motor abilities. This raises the research question of whether the same level of usability could be achieved by employing appropriate training with the commonly used VE input devices (joystick and mouse) in comparison to the employment of the multi-disciplinary design methodology for the selection or development of usable input devices.

Are there any positive effects of the upper body movement, which is required for controlling VE navigation with VR1?

It has been suggested, by the author, that the upper body movement, which is required for controlling VE navigation with VR1 could have the following benefits: increased sense of immersion in the VE; physiological exercise and improvement of spatial and directional awareness. The latter possibility, improvement of spatial and directional awareness, is based on the comments made by the physiotherapists and occupational therapists who were involved in the development of the Mojo interactive seat (see Chapter 2: 2.3.3 Solutions), which also requires upper body movement to control VE navigation.

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Appendix A

- Paper 1: Computer Interface Design to Virtual Environments for People with Learning and Physical Difficulties
    - ICCHP (International Conference on Computers Helping People with Special Needs) 2000

- Paper 2: Access to Virtual Learning Environments for People with Learning Difficulties
    - ICDVRAT (International Conference on Disability, Virtual Reality and Associated Technology) 2000

- Paper 3: Control of Virtual Environments for Young People with Learning Difficulties
    - Journal of Disability and Rehabilitation (*in press*)

- Paper 4: Control of Virtual Environments for People with Intellectual Disabilities
    - CWUAAT 2002 (1st Cambridge Workshop on Universal Access and Assistive Technology)

- Accepted Abstract: Design of Virtual Environment Input Devices for People with Learning Disabilities – a User-Centred Approach
    - ICDVRAT (International Conference on Disability, Virtual Reality and Associated Technology) 2002

COMPUTER INTERFACE DESIGN TO VIRTUAL ENVIRONMENTS FOR PEOPLE WITH LEARNING AND PHYSICAL DIFFICULTIES

Tanja Lannen and Dr. David Brown

Virtual Environments are a recent computer aided learning tool, with implications for both mainstream and special education. By definition, they are three-dimensional computer simulations, which respond in real time to the activity of their users. An evaluation of virtual learning environments, developed to teach independent living skills to people with learning difficulties, showed that they can provide a motivating learning tool, which can represent real world tasks and through which, users are able to learn some basic skills. However, recent research has highlighted usability problems with the computer interface devices, which are currently used, by people with learning and physical difficulties, to navigate and interact with the virtual environments. Due to the prevalence of fine motor difficulties within this user group, several individuals have found the devices difficult to control. This paper describes the design and development of a new interface device, Mojo, developed to increase accessibility to virtual environments for many people with physical and learning disabilities.

1. Introduction

1.1. Virtual Environments

Virtual environments are three-dimensional computer simulations, which respond in real time to the activity of their users. When exploring a virtual environment a user may find objects with which to interact. The sense of presence within the virtual environment is dependent on the input and display devices used. A high level of participant immersion can be achieved using a head-mounted display with a specialised input device, such as a data-glove. Desktop virtual environment systems are also in widespread use. These systems utilise a computer monitor to display the virtual environment and standard input devices, such as a joystick, mouse or keyboard. This hardware combination can also lead to a sense of presence. Generally, desktop systems are preferred when working with people with special needs due to the unresolved health and safety issues and high cost associated with head-mounted display units.

An initial use of virtual environment technology was in flight simulators, in order to teach the necessary skills safely. Virtual environments have now expanded their application to architecture, medicine, industrial training, education and many more fields. Stuart & Thomas [8] listed some educational applications of virtual environments: exploration of places, which are normally inaccessible, such as the jungle or ocean floor; experience of things that are normally invisible or inaccessible, such as molecules or planets.

1.2. Virtual Environments for People with Special Needs

Recent research indicates numerous benefits in the use of virtual environments for individuals with special needs [3]. They encourage active involvement in learning and give the user control over the learning process. They facilitate playful activity, by allowing individuals to learn by making mistakes, without suffering the consequences of their errors. Virtual environments can also avoid abstract thought, which is particularly difficult for people with learning difficulties, who are often described as 'concrete thinkers' [5]. Finally, they can minimise the effects of many physical disabilities and allow students to take part in activities or visit places that are inaccessible to them in real life.

There have been some interesting developments in the specification of training and education environments for people with special needs. The Makaton virtual learning environments examined an alternative way in which to teach the Makaton symbols and signs, a communication system used by people with severe learning difficulties. In a user-based evaluation of these environments it was found that their use promoted self-directed activity [7]. The Virtual City is a set of virtual learning environments for developing independent living skills in people with learning difficulties [9] and includes a house, a café, a supermarket and a transport system (see Fig. 1). More recently, virtual learning environments are being developed at the Nottingham Trent University to teach work skills to socially excluded groups of people. Some of these virtual environments will be accessed via a dedicated web server.

Figure 1. *The Virtual City – café, supermarket and transport system*

An evaluation of the Virtual City showed that virtual environments can provide a motivating learning tool, which can represent real world tasks and through which, users are able to learn some basic skills. However, it was also found that individuals differed in the amount of support they required in order to use the input devices: joystick for navigation tasks; mouse for interaction tasks [2]. Studies on the most appropriate methods of virtual environment control for people with learning and physical difficulties have been conducted. Hall [6] concluded that a joystick, limited to two simultaneous degrees of freedom, had the greatest utility in navigation. A study by Brown et al [1] evaluated a set of interaction and navigation devices, for use by students with learning and physical difficulties, from a range of affordable and robust devices commonly used at special schools. It was found that the joystick was more suitable for navigation tasks than the keyboard and mouse. The touch-screen and mouse were assessed for interaction tasks but neither of these devices rated best, although the touch-screen was difficult to calibrate. It was found that due to the prevalence of fine motor difficulties in this user group, several individuals found the devices difficult to control. This study revealed the following requirements for future input device design or modification: they should be operable by people with fine motor difficulties, modifiable, robust and affordable. These requirements triggered the design and development of Mojo: a navigation device operable with gross motor movement.

2. Mojo

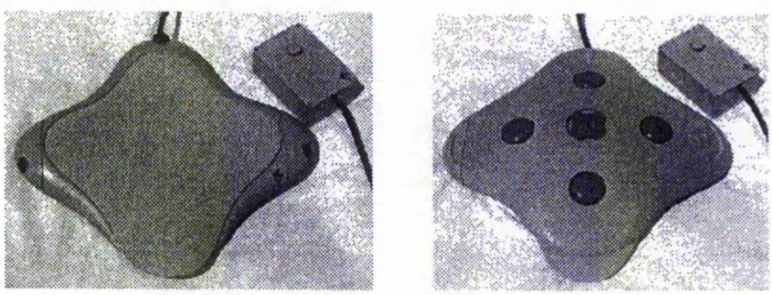

Figure 2. *Mojo – the interactive seat*

Mojo (see Fig. 2) is an interactive seat that is designed to enable people with learning and physical difficulties to explore virtual environments through movement. As previously stated, many people find it difficult to use a joystick or mouse because they have poor fine motor control. These people may be able to use Mojo as it requires lower body control in operation. The movements that Mojo encourages could also benefit users therapeutically, by improving their spatial awareness and gross motor control.

For operation, the user sits on the device, which can be placed on a wheelchair seat, a chair or the floor. The user can then rock from side to side, forward and back onto the motion sensors, which transfer the user's movement to the virtual environment. The sensitivity of the product can be adjusted to suit the ability and weight of the user. This can allow very slight movements to be detected. Switches on each side of the device can be used to increase its degrees of freedom. Alternatively, external switches, which are more suited to the abilities of the user, can be plugged in to the device. The prototype can also be used to control multi-sensory equipment/reward toys, when they are plugged into the control box.

3. Development Methodology

3.1. Technology Review

A review of existing virtual reality and assistive computer interface technology was conducted. The benefits of this were to identify any further product requirements and to inspire concept design and development. The most relevant devices identified in the virtual reality review were the 'position tracker' and the 'motion platform'. Motion platforms can simulate the physical characteristics of movement: tilt, pitch, rumble, acceleration, stopping, etc. Their use has been generally limited to arcade games or very expensive flight and motion simulators. A variety of adaptive computer technology is widely available to meet the needs of disabled computer users. The review of this technology revealed several interesting devices: head tracking; eye-tracking; foot mouse.

3.2. User Group

The primary goal was to design an input device, which would give virtual environment access to people with fine motor difficulties. Motor difficulties are usually connected with conditions where damage has been caused to the central nervous system, such as: cerebral palsy, multiple sclerosis, muscular dystrophy and dyspraxia. A number of students, with learning and physical difficulties, were selected to be part of a user group that would evaluate the developing interface device. During concept design, special needs experts were interviewed in order to advise and monitor the interface development.

3.3. Input Device Requirements

The main device requirements were identified as:

- Operable by people with learning difficulties
- Operable by people with fine motor difficulties
- Safe and comfortable to use
- Modifiable, robust, affordable and motivational

3.4. Concept design 1

A range of concepts were generated, which satisfied the main device requirements. The computer interface knowledge gained from the technology review also contributed to the concept design. Two of these concepts were the 'Cradle Chair' and the 'Tilting Platform 1' (see Fig. 3). Concept modifications and new ideas were identified during interviews with special needs experts from two special schools. An adaptation to the 'Tilting Platform 1' concept was suggested: the user's wheelchair or special chair can be fixed to the platform, so that they remain supported.

3.5. Concept Design 2

A further range of concepts were generated, utilising the ideas identified in the above interviews, i.e. 'Tilting Platform 2' and 'Chair Pads' (see Fig. 3). These concepts were then shown to special needs experts for further modification and idea generation. Great interest was raised in 'Tilting Platform 2', with suggestion that the operational movements could enhance spatial awareness and trunk control. However, a physiotherapist put forward a further change to this concept: the user should sit directly on the platform, so that concentrated weight transfer, using trunk control, could be achieved. This triggered the development of 'Tilting Platform 3' alongside several other ideas, including the 'Tracking Strap' concept (see Fig. 3).

3.6. Concept Selection

The chosen concept for further development had to satisfy the main product requirements and many of the concepts appeared to satisfy these criteria. However, the 'Tilting Platform' idea received the highest level of interest from the special needs experts. A further factor in favour of this idea was its motivating method of operation. Therefore the final Tilting Platform, number 3, was chosen for further development.

3.7. Test Prototype

An initial prototype was developed to evaluate the 'Tilting Platform 3' concept (see Fig. 4). For operation, the user sits on the prototype, which is placed on the floor, in a wheelchair or other chair, and transfers his/her body weight to the left, right, forward or backward. By leaning in either of these ways, the user activates a microswitch, which lights the corresponding LED (Light Emitting Diode) on the direction indicator.

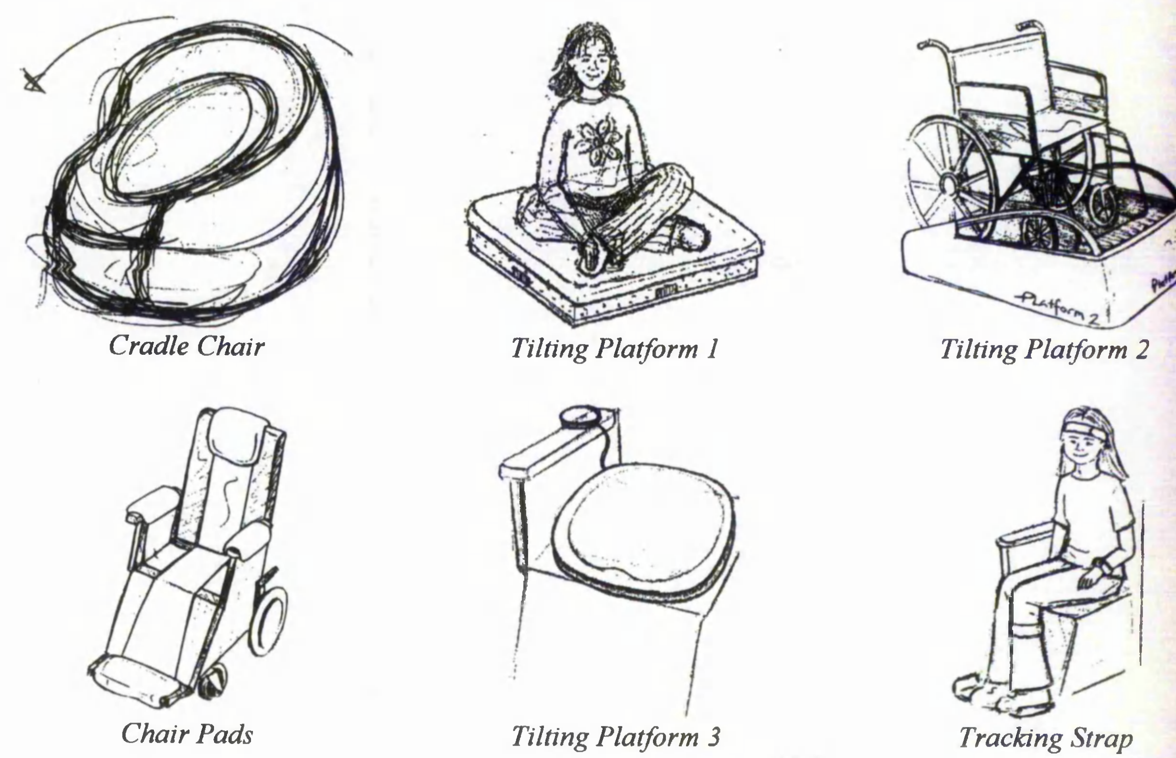

Figure 3. *A selection of concept designs*

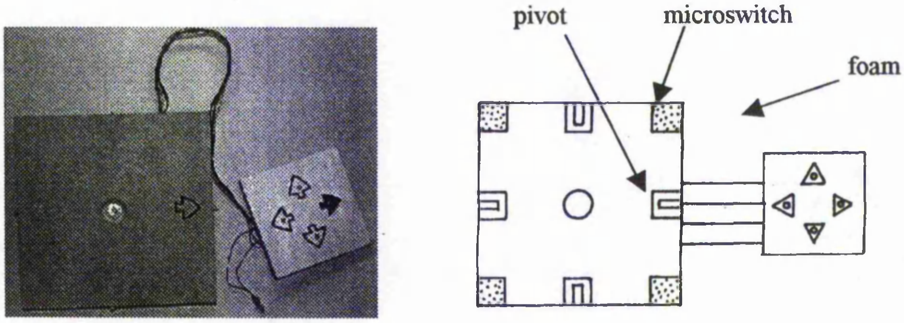

Figure 4. *Test prototype*

Evaluation

The test prototype was evaluated by students with various learning and physical difficulties. 5 out of the 6 subjects tested were able to use the device to some degree. The occupational therapist who was present, suggested that the individual, who experienced difficulty, might be able to use the device if he was taught how to move from his hips. This evaluation showed that the operation movements were achievable and motivational and highlighted the therapeutic benefits, which the concept may induce. Additionally, it identified the need for a sensitivity control, so that the prototype can be adapted to suit the ability and weight of the individual.

4. Final Prototype

4.1. Main Product parts:

- moulded seat pad
- shallow domed base with flat 'at rest' area
- 4 motion sensors (Force Sensitive Resistors)
- buttons (further direction control)
- sensitivity control potentiometer (in separate control box)
- PIC 16C74 Microcontroller (in separate control box)
- MAX232 Line Driver (in separate control box)
- facility to control multi-sensory equipment/reward toys (in separate control box)

4.2. System Input

A PIC 16C74 Microcontroller chip lies at the heart of this system. The PIC has been programmed to read the inputs, from the device's sensors and buttons, and control the subsequent output, primarily to a PC. The user's movement is sensed using force sensitive resistors (FSRs). Four of these sensors, F1, F2, F3 and F4, are positioned on the base of the prototype to sense left, right, forward and backward movement respectively. A vacuum-formed plastic button is joined to each sensor for actuation.

4.3. System Output

The PIC16C74 has a Universal Synchronous Asynchronous Receiver Transmitter (USART). For this prototype, the USART has been configured as a full duplex asynchronous system so that it can communicate with a personal computer.

A MAX232 chip (line driver) is positioned between the USART of the PIC and the serial connector, to convert the 5v TTL/CMOS outputs from the PIC into 9v RS-232 inputs to the serial port. A device driver was written for the prototype, which links the serial inputs from the device to the virtual environment, by carrying out the following operations:

- Open the serial port
- Flush the serial port
- Get a byte from the serial port

4.4. Ergonomics

The surface of the prototype is gently moulded to provide an appropriate distribution of pressure beneath the buttocks. The base is gently domed, with a flat central area so that the device can be at rest. Straps for securing the device to a chair can be attached at the centre of the base. Handgrips form part of the base moulding and a button is positioned close to each handgrip for thumb activation. The sides of the prototype can be removed, so that it can be used in smaller wheelchairs. The dimensions of the prototype accommodate users in the age range 7-11.

5. Final Prototype Evaluation

5.1. Navigation tasks

The aim of the evaluation was to compare Mojo with a joystick for navigation tasks within virtual environments, in order to assess which device proves to be the most successful. A number of students with learning and physical difficulties were selected from two special schools to take part in the evaluation. The user group was asked to complete navigation tasks within a virtual ski environment and a virtual supermarket. In the former environment the students were required to navigate through four flagged gates on a virtual ski slope. In the virtual supermarket the students were asked to complete the following tasks:

- Collect the supermarket trolley
- Enter the supermarket
- Collect items from the supermarket shelves
- Go to the checkout
- Return the supermarket trolley

5.2. Assessment Measures

The assessment measures, which were used in the input device evaluation by Brown et al [1] were utilised in this study. The virtual ski environment assessment measures were:

- Errors: hitting a gate; missing a gate; failing to attempt to go through a gate
- Disorientation and rectification: how many attempts, counted as single moves of the input device, the student requires to rectify him/herself
- Button Misuse: it was explained to the students that the buttons were not required for this experiment, therefore, any use of them was deemed to be an error

The assessment measures for the virtual supermarket were:

- Assistance required: prompting the student; doing part of the task; doing the complete task
- Time taken to: collect the trolley; enter the supermarket; return the trolley

Further measures of *harshness* and *user engagement* were assessed with both virtual environments: the degree of harshness used by the student on the input device was seen to be a good indication of frustration and user engagement would indicate to what degree the student was enjoying his/her interaction. Facial expression was also observed as an indication of user enjoyment and any relevant user comments were recorded during the evaluation. The results of this evaluation will be presented at the conference.

6. Future Research

Further research is required in order to increase accessibility to virtual environments for people with special needs. The author is currently employing a user-centred design methodology to design, develop and evaluate a virtual environment interface for people with learning difficulties.

The methodology was formed by combining established guidelines on user-centred design [4, 10] with contemporary human-computer interaction, product design and virtual reality research. Central to this design process is 'usability', a crucial factor in the production of a successful human-computer interface. Usability is defined in ISO 9241 (the British standard giving guidance on usability) as 'the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use'.

In a usability evaluation, a user group will test the resulting prototype(s) with appropriate virtual environments. The results from this user-based assessment will be continually fed into concept design, until the design objectives have been attained. The completion of this study should result in the production of a virtual environment interface for people with learning difficulties, which satisfies the usability standard ISO 9241.

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Access to Virtual Learning Environments for People with Learning Difficulties

Tanja L Lannen, David J Brown and Heather M Powell

Department of Computing, the Nottingham Trent University,
Burton Street, Nottingham, England

tanja.lannen@ntu.ac.uk, david.brown@ntu.ac.uk, heather.powell@ntu.ac.uk

ABSTRACT

An evaluation of virtual learning environments, developed to teach independent living skills to people with learning difficulties, found that individuals differed in the amount of support required to use the input devices. This paper describes the employment of a user-centred design methodology to design, develop and evaluate a virtual environment hardware interface for people with learning difficulties. Central to this methodology is 'usability', a crucial factor in the production of a successful human-computer interface. The completion of this study should result in the production of a virtual environment interface for people with learning difficulties, which satisfies ISO 9241 (the British Standard giving guidance on usability).

Keywords: Learning difficulties, input device, user-centred design, usability

1. INTRODUCTION

There have been some interesting developments in the specification of training and education environments for people with special needs, including the Virtual City: a set of virtual environments developed to teach independent living and social skills to people with learning difficulties (The Shepherd School, 1998). In an evaluation of the Virtual City, it was found that individuals differed in the amount of support required to use the input devices: joystick for navigation tasks; mouse for interaction tasks (Cobb et al, 1998). Studies on the most appropriate methods of virtual environment control for people with learning difficulties have been conducted. Hall (1993) concluded that a joystick, limited to two simultaneous degrees of freedom, had the greatest utility in navigation. A further study evaluated a set of interaction and navigation devices, from a range of affordable and robust devices commonly used in special schools (Brown et al, 1997). In this study, the joystick was found to be more suitable for navigation tasks than the keyboard and mouse. The touch-screen and mouse were assessed for interaction tasks but neither of these devices rated best, although the touch-screen was found difficult to calibrate. From this research, it is clear that there is a need for further investigation into virtual environment access for people with learning difficulties.

2. INPUT DEVICE EVALUATION

2.1 Aims

- to evaluate the usability of the joystick for navigation tasks and the mouse for interaction tasks within virtual environments, for people with learning difficulties
- to obtain any usability guidelines for future virtual environment input device development

2.2 User Group

A user group was selected from the pupils who attend the Shepherd School in Nottingham. The user group attributes were as follows: size of group - 14; gender - 7 female and 7 male; age range - 8 to 19; cognitive ability - 2 moderate/severe and 12 severe learning difficulties; physical ability - co-ordination, gross-motor and fine-motor difficulties. 6 students had previous experience with virtual environments, 6 had used the joystick and 5 had used the mouse before.

2.3 Environment

The evaluations took place at the Shepherd School, in the 'Cyber Café' room. For some of the evaluations, the room was quiet and mostly free from distraction. During the majority of the evaluations, other students would come and go from the room, but would not attempt to disturb the subject.

2.4 Equipment

A colour computer monitor was used to display the virtual environments and a standard 2-button mouse was used for interaction tasks. 10 students used the Axys joystick (Suncom Technologies) and 4 students used the Wingman joystick (Logitech) for navigation tasks. The stick on the Wingman joystick is much taller and wider than the Axys joystick and is shaped to fit the hand.

2.5 Task

Each student was asked to complete navigation and interaction tasks, using the joystick and mouse respectively, within a virtual factory, café or supermarket. A demonstration of the devices and tasks was given before commencing the evaluations.

2.6 Assessment Measures

- Misuse of device: non-task related movement, harshness, pressing the wrong buttons, any other points
- Support required: spoken instruction, physical assistance, any other points
- Physical ability: sufficient strength, able to grip properly, any other points
- Workplace: able to reach, any other points
- Attention: on task, on device, on other
- User comments/reactions: positive, negative

2.7 Results

When performing navigation tasks with the joystick, 7 students showed controlled use of this device and 6 appeared to be holding the stick comfortably. The difficulties, which some of the students experienced with the joystick are listed in Table 1. The main usability problems experienced with the joystick were found to be: random movement; left/right movement causing too much rotation in the virtual environment; trying to use the device for interaction tasks and difficulties in gripping the joystick.

For interaction tasks, 6 students used the mouse quite well, with 7 gripping the device properly. Some students rested their hand on top of the device when using it, instead of gripping around the sides. As was found with the joystick, random movement of the device occurred and 3 students repeatedly pressed the mouse button, rather than just pressing it once and releasing it. One student required the evaluator to hold the mouse still, so that he could press the button and interact with the virtual environment. These, and further usability difficulties, which were observed are listed in Table 1.

Details obtained from the other assessment measures, i.e. support required, which were considered to effect the usability of the system are also listed in Table 1. Additionally, this table lists some suggested design guidelines for future virtual environment input device development, which have also been summarised in Table 2. Examples of these design guidelines are:

- Clear, understandable operation
- Consider the physical abilities of the user group
- Ergonomic design

These requirements highlight the importance of considering the cognitive and physical attributes of the user group when designing a product to meet their needs. In user-centred design, product developments are driven from user requirements, rather than from technological capabilities (USERfit, 1996). Therefore, it was decided that a user-centred design methodology should be employed, in order to design, develop and evaluate a virtual environment interface for people with learning difficulties.

Table 1. ***Usability factors identified in the Input Device Evaluation and suggested design guidelines for future virtual environment system development (in italics).***

Navigation Random movement of device, disorientation - *Clear, understandable operation* Too much left/right rotation, spinning - *Device more resistive to movement (may help to prevent some disorientation)* Trying to use for interaction tasks - *Functional clarity for achieving navigation and interaction tasks* Button misuse - *Not easy to press buttons by mistake* Base held still by evaluator - *Ensure that base of device remains stationary during operation* Physical help with some tasks, alignment guidance - *Able to use the device independently* Used two hands, tight grip - *Ergonomic design of device* *Interaction* Random movement of device - *Clear, understandable operation* Frequent pressing of buttons, pressing wrong button - *Not easy to press buttons by mistake* - *Only possible to press buttons which are required* Physical help with some tasks, held still to press button - *Able to use the device independently* - *Consider physical abilities of the user group* Not gripping around the sides of the device - *Ergonomic design of the device*	*Further assessment measures* Prompting as to which device to use for a task - Functional clarity for achieving navigation and interaction tasks - *Only have one input device for navigation and interaction tasks* Encouragement, some distraction/distracted - *The device gives rewarding feedback* - *The device is motivating to use* Weak grip, shaky hand/arm - *Consider physical abilities of the user group* Desk too high - *Adjustable workstation* In Major Buggy - *Consider accessibility to the workstation* Fidgets in seat - *Workstation helps to engage the user* - *Integrated workstation* Some distraction/distracted - *Develop interesting, motivating and age appropriate virtual environments* Attention on devices when using them - *Device doesn't distract attention for the VE* - *Device is transparent* Attention on devices when switching between them - *Only have one input device for navigation and interaction tasks* - *The user does not have to keep locating a device* Frustration with tasks - *Ensure virtual environments are age appropriate*

Table 2. *Summary of the suggested design guidelines for future virtual environment system development*

- **Clear, understandable operation of the device**
- Functional clarity for achieving navigation and interaction tasks with the device
- The device is more resistive to movement (may help to prevent some disorientation)
- Only have one input device for navigation and interaction tasks
- Not easy to press buttons by mistake
- Only possible to press buttons which are required
- The device can be used independently
- Ensure that base of device remains stationary during operation
- Ergonomic design of device
- Consider the physical abilities of the user group
- The device gives rewarding feedback
- The device is motivating to use
- The device is transparent, i.e. doesn't distract attention from the virtual environment
- Adjustable and accessible workstation
- Workstation helps to engage the user
- Develop interesting, motivating and age appropriate virtual environments

3. USER-CENTRED DESIGN

3.1 Introduction

Central to this design process is usability, a crucial factor in the production of a successful human-computer interface. The usability of a product is defined in ISO 9241, part 11 (the British Standard giving guidance on usability) as 'the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use'. According to the ISO 13407 standard (human centred design processes for interactive systems) the key activities in user-centred design are:

- understand and specify the context of use
- specify the user and organisational requirements
- produce design and prototypes
- carry out a user-based assessment

In user-centred design, an iterative design process is employed, with the cycle of activities being repeated until the usability objectives have been attained (Daly-Jones et al, 1999).

3.2 Understand and Specify the Context of Use

This activity can be achieved by conducting a Usability Context Analysis (UCA), which involves the following research:

- User analysis: the product should be designed with reference to the characteristics of the end-users. Important factors to identify include the physical, cognitive and perceptual abilities of the user group.
- Task analysis: this should be carried out to identify the major productive goals, which a user can achieve, using the product.
- Environment analysis: it is important to understand the environment in which the product will be used, and how that environment should be constructed, so as to facilitate rather than impede the use of the technology (USERfit, 1996). This study involves an analysis of the organisational, technical and physical factors of the environment in which the product will be used.

3.3 UCA – Virtual Environment Input Device for People with Learning Difficulties

The UCA guidelines, available from Serco Usability Services, were utilised for this research. These guidelines include a 'context questionnaire', which covers the user, task and environment analysis. Initially, a 'Usability Team' was formed to advise and monitor the project development. This multi-disciplinary team included: project advisors; the design engineer; human-computer interaction and special needs experts; a usability specialist and an occupational therapist. To date, the User Analysis stage of the UCA has been completed and is described in the following section.

4. USER ANALYSIS

4.1 User Group

A user group of 21 students was selected from pupils who attend the Shepherd School in Nottingham. 14 of these students had previously participated in the Input Device Evaluation (see section 2). Students were selected who seemed to enjoy using computers and showed an understanding of how to use the virtual environments. The students ranged from age 7 to 19, with 5 primary, 8 secondary and 8 from the 16+ department of the school (9 of the students were female and 12 were male).

4.2 Skills and Knowledge

Details of the students' experience, with input devices, virtual environments and computers in general, was obtained through the Input Device Evaluation (see section 2) and the students' annual monitoring forms:

- Input devices: some of the students could use the joystick, mouse, trackball and keyboard and the majority of the user group could use a touch-screen and switch.
- Virtual environments: 6 students had previous experience.
- Computers: 4 students can switch on the computer and load a program and most of the students are motivated when working on a computer.

4.3 Cognitive Abilities

In order to gain some understanding of the cognitive abilities of the user group, two established assessment tests were used:

- The BPVS-II (British Picture Vocabulary Scale): a test of receptive English vocabulary, which correlates highly with verbal intelligence
- The MAT-SF (Matrices Analogies Test – Short Form): a test of non-verbal reasoning

4.3.1 Results. From the BPVS-II, 19 of the user group achieved in the extremely low score range for receptive English vocabulary, with two of the students scoring slightly higher and bordering the extremely low to moderately low score range (female aged 8:04, male aged 16:11). From the MAT-SF, 18 of the students achieved in the extremely low score range for non-verbal reasoning. In this case, 2 students scored in the low score range (female aged 8:06, male aged 8:06) and 1 student achieved an average score for his age (male aged 7:05). These measures are indicative of the students' cognitive abilities and in have shown that the students in the user group are generally in the moderate/severe level of cognitive functioning.

4.4 Physical Abilities

Details of the gross and fine motor abilities of the user group were obtained through the QNST-II (Quick Neurological Screening Test) and the students' annual monitoring forms. The tasks on the QNST-II provide an opportunity to observe the students' skill in controlling gross and fine muscle movements and their motor planning and sequencing abilities.

4.4.1 Fine-Motor Ability. 11 students were observed to have a good pen grip when writing and drawing and 15 showed good finger dexterity. A clumsy pen grip was noted in 10 students, with 1 student displaying hand tremor, which enhanced her difficulty in writing and drawing. Further fine-motor difficulties, which were observed, are listed in Table 3.

4.4.2 Gross-Motor Ability. Most of the user group members are independently mobile and over half showed good upper extremity movement and ability to reach. 3 of the students walk with an unsteady gate and 1 is normally in a special chair or using a walker. Co-ordination, motor planning and balance difficulties were observed in the majority of the students. Further gross-motor difficulties, which were observed, are listed in Table 3.

4.5 Perceptual Abilities

Details of the perceptual abilities of the user group were also obtained through the QNST-II, with further input from the students' educational files:

- Visual perception: all members of the user group have normal vision, though 7 are required to wear glasses to achieve this.
- Auditory perception: most of the students have normal hearing, though 6 have a history of ear infection or hearing difficulties.
- Visual-motor perception difficulties: there were many difficulties observed during the QNST-II, which can be categorised under this heading. The main difficulties experienced were with spatial awareness, ordering and sequencing, mixed laterality and bilateral tasks.

4.6 Further User Attributes

4.6.1 Communication. All members of the user group use Makaton signing, in order to communicate with other students and their teachers. There is a wide range of communicative ability within the group. A few of the students have good verbal communication, whereas others are limited to signs, gestures and some vocalising.

4.6.2 Behaviour and motivations. Almost half of the students displayed distractibility and a few showed a lack of self-confidence. The virtual environment system should aim to gain the full attention of its user and to build his or her confidence. A list of activities, which the students enjoy, was also obtained, e.g. music, art, sport and writing.

Table 3. *The physical attributes of the user group*

Fine-Motor Ability	*Gross-Motor Ability*
Good fine-motor ability - Good pen grip: 11 - Can isolate finger press: 15 Fine-motor difficulties - Clumsy pen grip: 10 - Motor planning difficulties: 19 - Motor tension: 4 - Slight hand tremor: 1 - Limited wrist movement: 6 - Wrist dip (muscle hypertension): 6 - Weak grip: 1 - Finger dexterity difficulties: 6	Good gross-motor ability - Independently mobile: 20 - Good upper extremity movement: 11 - Good reach ability: 15 Gross-motor difficulties - Unsteady gate: 3 - Uses a walker: 1 - Unsteady arm movement: 2 - Rigid arm: 1 - Difficult to fully stretch right arm: 1 - Co-ordination: 14 - Motor planning: 18 - Balance: 16

5. CONTINUED RESEARCH

Following the completion of the UCA, the user requirements for the input device will be identified. These will then be translated to design objectives to produce a 'product design specification'. The suggested design guidelines, identified from the Input Device Evaluation (see section 2) will also be incorporated into the design specification. A review of existing computer interface technology, including assistive computer access methods and virtual reality interfaces, will be conducted to identify any existing devices, which with adaptation could provide a potential solution and to identify technological opportunities for satisfying the design requirements in novel ways. The design specification will be used to guide both concept and prototype design, by checking the developing input device(s) against the design objectives, and established techniques for concept and prototype development will be employed. Storyboards of the concepts will be reviewed by the Usability Team, in order to modify the design before commencing to the prototyping stage.

In a usability evaluation, the User Group will test the prototype(s) with appropriate virtual environments. The results from this user based assessment will be continually fed into concept design, until the design objectives, outlined in the design specification, have been attained, see Fig. 1. The completion of this study should result in the production of a virtual environment input device for people with learning difficulties, which satisfies ISO 9241 (the British Standard giving guidance on usability).

Acknowledgements: The authors would like to thank the Shepherd School for their co-operation with this research.

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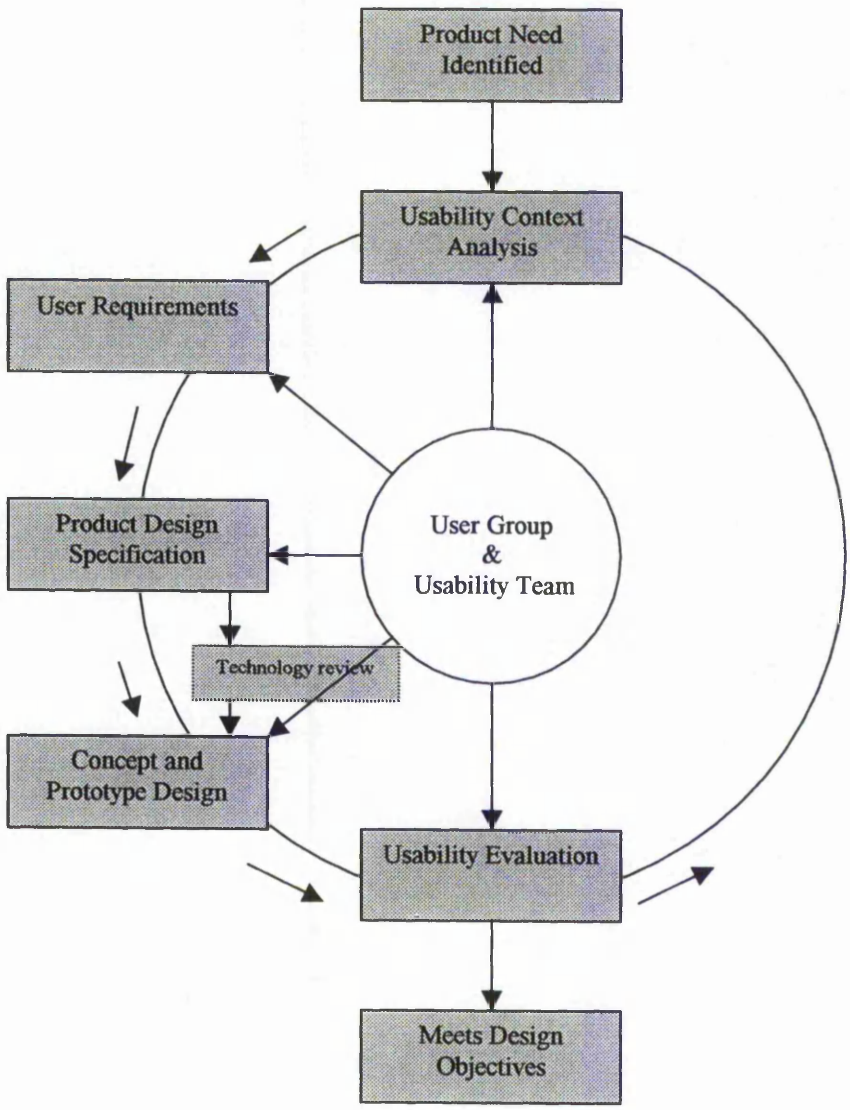


Figure 1. *The user-centred design cycle*

Control of virtual environments for young people with learning difficulties

Tanja Lannen, Dr. David Brown and Dr. Heather Powell

Dept. of computing, Nottingham Trent University, UK, Tanja.lannen@ntu.ac.uk

Abstract

Purpose: The objective of this research is to identify the requirements for the selection or development of usable virtual environment (VE) interface devices for young people with learning difficulties.

Method: A user-centred design methodology was employed, to produce a design specification for usable VE interface devices. Details of the users' cognitive, physical and perceptual abilities were obtained through observation and normative assessment tests.
Conclusions: A review of computer interface technology, including virtual reality and assistive devices, was conducted. As there were no devices identified that met all the requirements of the design specification, it was concluded that there is a need for the design and development of new concepts. Future research will involve concept and prototype development and user-based evaluation of the prototypes.

Introduction

Recent research in virtual environment (VE) applications for people with learning difficulties has highlighted usability difficulties with the computer interface devices, which are used to perform the VE tasks. For example, from an evaluation of VEs, developed to teach independent living skills to people with learning difficulties, it was found that individuals differed in the amount of support required to use the input devices; joystick for navigation and mouse for interaction [1]. This paper describes research undertaken to identify the requirements for the selection or development of usable VE interface devices for young people with learning difficulties.

VIRTUAL ENVIRONMENTS

VEs have been found to be of educational benefit for people with learning difficulties. Before describing these benefits, what are VEs? They are three-dimensional computer simulations, which respond in real time to the activity of their users, see figure 1. One of the first applications of VE technology was in flight simulation to train pilots within a safe environment. Their use is continually progressing in many areas, such as architecture, medicine, rehabilitation and education. There are two independent phases of operation within a VE: navigation and interaction. Navigation, with 2 degrees of freedom, allows movement forwards, backwards and turning to the left or right. Interaction includes activating VE objects (i.e. opening a door), moving VE objects from one place to another or using one object with another (i.e. using a spoon to take some sugar from a sugar bowl). The sense of presence within a VE is dependent on the input and display devices used. A high level of participant immersion can be achieved using a head-mounted display with a specialised input device, such as a data-glove. Desktop VE systems are also in widespread use, which utilise a computer monitor to display the VE and standard input devices, such as a joystick, mouse or keyboard, see figure 2. This hardware combination can also lead to a sense of presence and generally, desktop systems are preferred when working with people with learning difficulties due to the unresolved health and safety issues and high cost associated with head-mounted display units.

Figure 1 The virtual city

VE BENEFITS

Research has indicated numerous benefits in the use of VEs for the education and training of people with learning difficulties [2]. They encourage active participation in learning and give the user control over the learning process. They facilitate playful activity, by allowing individuals to learn by making mistakes without suffering the consequences of their errors. VEs are described in terms of realistic and graphical representations of the real world. Hence, they avoid abstract thought, which has been found to be particularly difficult for people with learning difficulties, who are often described as 'concrete thinkers' [3]. Finally, they can minimise the effects of many physical disabilities and allow students to take part in activities or visit places that might be inaccessible to them in real life.

MOST SUITABLE INPUT DEVICES

Studies on the most appropriate methods of VE control for people with learning difficulties have been conducted. Hall [4] concluded that a joystick, limited to two simultaneous degrees of freedom, had the greatest utility in VE navigation tasks. A study by Brown et al [5] found that the joystick was more suitable for navigation tasks than the keyboard or mouse. The touch-screen and mouse were assessed for interaction tasks and the students coped very well with both devices, however, difficulties were found in using the touch-screen to interact with small objects and with calibration of this device. From these studies it can be concluded that, from the range of input devices tested, the joystick and mouse are the most suitable navigation and interaction devices respectively.

USABILITY DIFFICULTIES

Neale et al [6] conducted an evaluation of VEs for the education of children with severe learning difficulties. The devices utilised in this study were the joystick for navigation tasks and the mouse or touch-screen for interaction tasks. It was found that:

- Restricted movement space was difficult to navigate and led to user frustration
- Teacher assistance was required for some interaction tasks

It is important to note that participant selection for this study was based partly on ability to control the input devices. Although the navigation difficulties found were software related, it is the author's belief that, the overall usability of the system would be enhanced by refining the input devices as well as the software interface. In the aforementioned study by Cobb et al [1], it was found that individuals differed in the amount of support required to use the input devices; joystick for navigation and mouse for interaction. It was also stated that navigation was found to be one of the most difficult tasks to do. This research by Neale et al [6] and Cobb [1] has shown that there are usability difficulties with the input devices, which have been found to be the most suitable for navigation and interaction tasks, from the range of devices tested by Hall [4] and Brown et al [5].

SOLUTIONS

In the aforementioned study by Brown et al [5] the following requirements for input device design or refinement were identified: operable by people with fine-motor difficulties, modifiable, robust, easy to calibrate and affordable. Lannen [7] developed a prototype interface device, the Mojo interactive seat, which meets some of these requirements: operable by people with fine-motor difficulties, modifiable and affordable, see figure 3. Mojo was compared with a joystick for control of a VE navigation task by students with moderate to severe learning difficulties, some of whom were also physically impaired [8]. From the results it was clear that less disorientation occurred when using Mojo, however, both devices would require refinement to provide an adequate solution to this human-VE interaction problem.

A review of computer interface technology, including virtual reality and assistive devices, was conducted. Assistive devices have been designed to improve access to computers for people with a wide range of disabilities, for example voice and gesture recognition, eye and head tracking and brain wave control. However, no research has been found which investigates the use of such devices for the control of VEs for people with learning difficulties. It has also been expressed that the cost of the technology mentioned would currently be too great for most individuals and some organisations [5].

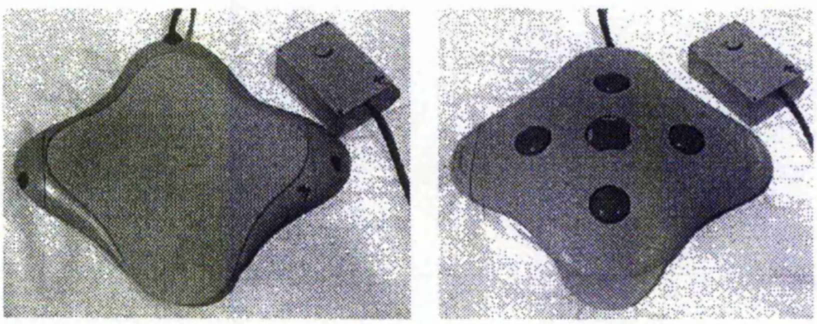


Figure 3 Mojo – interactive seat for VE navigation

CONCLUSION

The research by Neale et al [6] and Cobb [1] showed that there are usability difficulties with the joystick and mouse, which were found to be the most suitable devices for people with learning difficulties to control VE tasks. However, this research was not specific about the kinds of difficulties that are experienced with these devices. Therefore it was decided that the next step would be to conduct a thorough evaluation of the joystick and mouse, in order to identify the specific usability difficulties experienced and to clarify how research should progress.

Input device evaluation

Aim
To identify the usability difficulties, which young people with learning difficulties experience when using the joystick and mouse for VE navigation and interaction tasks respectively

User Group
14 students were selected from the Shepherd School in Nottingham to form the user group. The user group attributes were as follows:

- Gender - 7 female and 7 male
- Age range - 7 to 19
- Cognitive ability - 2 moderate/severe and 12 severe learning difficulties
- Physical ability - co-ordination, gross-motor and fine-motor difficulties

Environment
The evaluations took place at the Shepherd School, in their 'Cyber Café' room. For some evaluations, the room was quiet and mostly free from distraction. During the majority of evaluations, other students would come and go from the room, but would not attempt to disturb the user.

Equipment
The VEs were displayed on a colour computer monitor and a standard 2-button mouse was used for interaction tasks. 10 students used the Axys joystick (Suncom Technologies) and 4 students used the Wingman joystick (Logitech) for navigation tasks. The stick on the Wingman joystick is much taller and wider than the Axys joystick and is shaped to fit the hand, see figure 4.

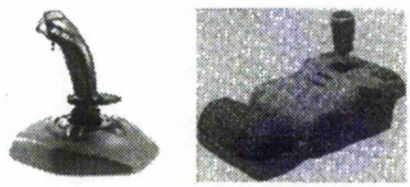


Figure 4 The Wingman joystick (Logitech) & the Axys joystick (Suncom Technologies)

Task
Each student was asked to complete navigation and interaction tasks, using the joystick and mouse respectively, within a virtual factory, café or supermarket. Demonstrations of the devices and tasks were given before commencing the evaluations.

Assessment Measures
- Misuse of device: non-task related movement, harshness, pressing the wrong buttons, etc.
- Support required: spoken instruction, physical assistance, etc.
- Physical ability: sufficient strength, able to grip properly, etc.
- Workplace: able to reach, etc.
- Attention: on task, on device, on other
- User comments/reactions: positive, negative

RESULTS: USABILITY DIFFICULTIES

Due to physical ability and device construction
Approximately half of the students in the user group were able to control the mouse and the joystick they evaluated quite well. However, this group still experienced usability problems with the devices: too much left/right rotation, button misuse, base held still by examiner and grip difficulties with the joysticks; base held still to press button and grip difficulties with the mouse. These difficulties are largely due to the construction of the devices and the physical abilities of the user group, rather than to the user's understanding of how to use each device. It was observed that the Wingman joystick is easier to grip than the Axys joystick, due to its size and shape, highlighting the importance of ergonomic design for increasing usability.

Due to cognitive ability
The difficulties experienced by other members of the user group are related to their cognitive understanding of how to use the devices: random movement and trying to use for interaction with the joysticks; random movement and frequent pressing of buttons with the mouse. To overcome these difficulties it may be necessary to gain a deeper knowledge of the users' cognitive and perceptual abilities, so that the devices can be refined to an appropriate level of understanding.

Due to task and environment
As the joysticks and mouse were not specifically designed to be used by people with learning difficulties to control VEs, there may be certain VE tasks for which they are more difficult to use. This is evident from this evaluation, as physical help was required with all of the devices to complete some tasks by many of the students. Finally, some members of the user group were distracted by other students and activities in the evaluation room. Design guidelines were suggested, which should help to focus the students' attention on the VE, for example, workstation helps to engage the user.

CONCLUSION

This evaluation has highlighted the importance of considering the physical and cognitive abilities of the user group, as well as the tasks that the user must complete with the input devices, and the environment in which the tasks will be performed, in order to develop a usable computer interface device. This theory is backed up by contemporary human-computer interaction (HCI) research, which also stresses that you should design for the user, the task and the environment [9]. In user-centred design, the first research activity performed is to 'understand and specify the context of use'. This can be achieved by conducting a Usability Context Analysis (UCA), which involves a user, task and environmental analysis. Therefore, it was decided that a user-centred design methodology would be employed in order to ascertain the requirements for the selection or design of usable VE input devices, for young people with moderate/severe learning difficulties.

User-centred design

METHODOLOGY

Usability is a crucial factor in the production of a successful human-computer interface and is central to the user-centred design process. The usability of a product is defined in ISO 9241, part 11 (the British Standard giving guidance on usability) as 'the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use'. According to the ISO 13407 standard (human centred design processes for interactive systems) the key activities in user-centred design are:

- Understand and specify the context of use
- Specify the user and organisational requirements
- Produce designs and prototypes
- Carry out a user-based assessment

The user-centred design methodology, which has been employed for this research project, was formed by combining established guidelines on user-centred design [10,11) with contemporary human-computer interaction and product design research:

1. Understand and specify the context of use
    - Usability Context Analysis (UCA) – user, task and environment analysis
2. Specify the user and organisational requirements
    - Identify design requirements (from UCA data)
    - Product Analysis (identify device attributes)

- Design Specification (DS)
3. Technology Review
   - Virtual reality, assistive and general computer interface devices
4. Produce concept designs and prototypes
5. Carry out a user-based assessment
   - Produce evaluation plan (including a Usability Specification)
   - Conduct Usability Evaluation
   - User-derived feedback used to refine the prototype(s)

Steps 1, 2, 4 and 5 are repeated until the usability metrics, outlined in the Usability Specification have been attained, see figure 5.

User Group and Usability Team

A user group of 21 students was selected from pupils who attend the Shepherd School in Nottingham. 14 of these students had previously participated in the Input Device Evaluation. Students were selected who seemed to enjoy using computers and showed an understanding of how to use the VEs. The students ranged from age 7 to 19, with 5 primary, 8 secondary and 8 from the 16+ department of the school (9 of the students were female and 12 were male).

A Usability Team was formed to advise and monitor the project development, by reviewing the UCA data, Design Specification, concept designs, Usability Specification and Usability Evaluation feedback. This multi-disciplinary team included: project advisors; the design engineer; human-computer interaction and special needs experts; a usability specialist and an occupational therapist.

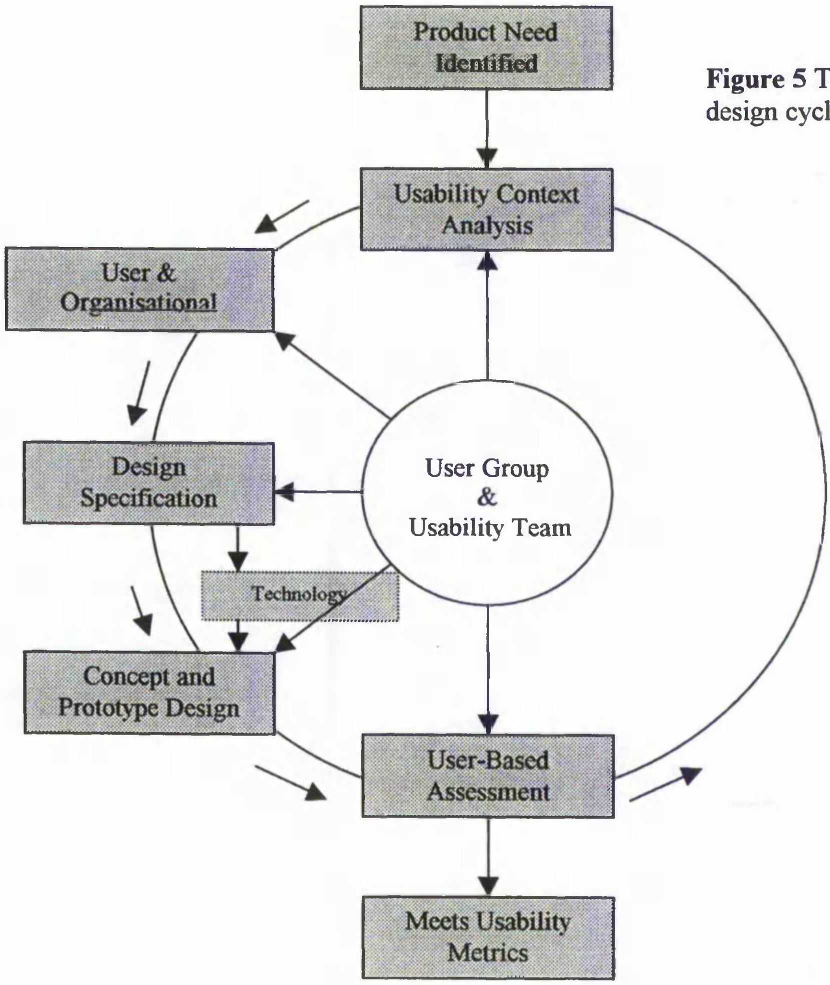


Figure 5 The user-centred design cycle

Understand and specify the context of use

This activity was achieved by conducting a Usability Context Analysis (UCA), which included a user, task and environment analysis. The UCA guidelines available from Serco Usability Services [12] and the relevant sections of the USERfit toolkit [11] were utilised for this research.

USER ANALYSIS

Information was gathered about each member of the user group, on their attributes, which could affect the usability of the input device: skills and knowledge; physical, cognitive and perceptual abilities; communication; behaviour and motivations. This data was obtained through various sources, including general observation, the students' educational files and normative assessment tests.

Cognitive ability
In order to gain some understanding of the cognitive abilities of the user group, two normative assessment tests were used:

- The BPVS-II (British Picture Vocabulary Scale): a test of receptive English vocabulary, which correlates highly with verbal intelligence
- The MAT-SF (Matrices Analogies Test – Short Form): a test of non-verbal reasoning

The results showed that the students in the user group are generally in the moderate to severe level of cognitive functioning.

Physical ability
Details of the fine and gross motor abilities of the user group were obtained through the QNST-II (Quick Neurological Screening Test) and the students' educational files. The tasks on the QNST-II provide an opportunity to observe the students' skill in controlling gross and fine muscle movements and their motor planning and sequencing abilities. Table 1 shows some examples of the student's fine and gross motor difficulties.

Table 1 **Examples of physical attributes of the user group**

Fine motor difficulties	Gross motor difficulties
Clumsy pen grip: 10	Uses a special chair: 1
Slight hand tremor: 3	Cerebral Palsy in legs and right arm: 1
Limited wrist movement: 6	Unsteady arm movement: 2
Motor planning difficulties: 19	Co-ordination: 14

Perceptual ability
Details of the perceptual abilities of the user group were also obtained through the QNST-II, with further input from the students' educational files. The main difficulties experienced were with spatial awareness, ordering and sequencing, mixed laterality and bilateral tasks (those involving use of both hands).

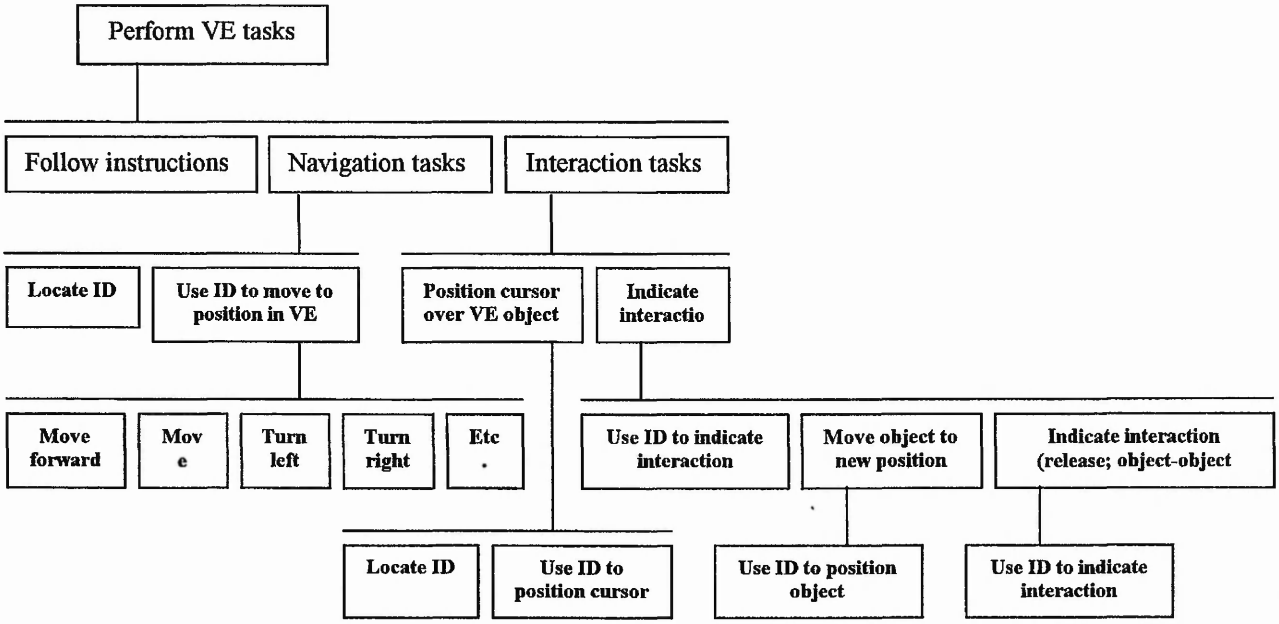


Figure 6 Hierarchical task analysis for VE control

Task analysis
A hierarchical task analysis, described by Dix, A et al [13], was carried out. In this process the primary tasks are broken down into subtasks and consequently the subtasks are further broken down, see figure 6.

Environment analysis
This study included an analysis of the organisational, technical and physical factors of the environment in which the product will be used. By gaining an understanding of these factors, a computer input device can be selected or developed to fit the task environment. Table 2 details the organisational factors.

Table 2 Organisational Environment

Organisation factor	Description
Group working	Work alone or in small groups (2 to 3); collaborative VEs
Assistance	Teacher/carer may be required
Interruptions	Other students may distract user
Performance monitoring	Computer software could record session/level reached; observation by teacher/carer
Performance feedback	Score or time taken given; intelligent agent reports 'well done', 'better luck next time'
Pacing	Able to work at own pace or against a clock

Specify the user and organisational requirements

Design requirements were extrapolated from the user, task and environment details obtained through the UCA. These requirements are design decisions, which should help to increase the usability of the computer input device(s) for the user group. A Product Analysis was then conducted in order to describe how the design requirements could be met through specific device attributes. Examples of the design requirements and device attributes are shown in table 3.

Table 3 Examples of Design Requirements and Device Attributes

UCA details	Design Requirement
Age range: 7:05 to 19:00	Age appropriate appearance (7 – 19)
Slight hand tremor	Will not detect unintentional movements
BPVS-II: Extremely low score range	Minimum user input for task completion
Spatial awareness difficulties	Provides visual cues to interface and function
Design Requirement	**Device Attributes**
Age appropriate appearance (7 – 19)	Modern style, attractive colours
Will not detect unintentional movements	Calibration to damp out unintentional movement
Minimum user input for task completion	One user action = one VE function
Provides visual cues to interface and function	Form indicates interface and function

Design Specification

The device attributes were collated in a design specification and separated into categories, for example, product appearance, ergonomic design, interface and functional assistance, cognitive and physical factors. Additional important aspects to a product's design, which contribute to its success, were added to the design specification. These include: performance, production, life in service and conformance requirements. The design specification is the main input to the concept design stage of the design process and therefore ensures that the design requirements are carried through to the production of a usable prototype.

Technology review

The primary aims of the technology review were to identify any existing computer interface devices that, with adaptation, could provide a potential solution and to identify opportunities for innovation. The following areas were reviewed, with reference to the design specification: virtual reality, assistive and general computer interface technology and gaming interface devices. A similar review was conducted before commencing the user-centred design process and hence without the design specification for reference.

FINDINGS

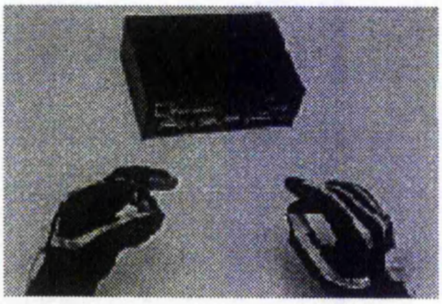
Several devices were found to possess a few of the device attributes in some of the categories. For *ergonomic design*, the Anir Ergonomic Mouse (Keytools) has been designed to help avoid repetitive strain injuries (RSI), to partly satisfy 'conforms to health and safety standards'. The FireStorm (ThrustMaster) is a games console, which satisfies 'form indicates interface' and 'haptic sensation with user action', which are *interface and function assistance* attributes. For *physical factors*, the Roller Joystick (Penny & Giles) 'provides assistance to user actions', with its latching drag feature and is of a 'robust construction'.

The Tilting Games Pad was found to be the 'closest concept', see figure 7, matching a significant number of the device attributes listed in the design specification. Visually, it would appeal to the user group, with its 'modern style, attractive colours'. The device is worn by adorning a glove, hence the 'form indicates the interface' (interface and function assistance). The user is required to tilt or wave their hand for the software to react, which suggests that the *cognitive factor* 'movement in VE same as user action' could be fulfilled. However, the user movements required may not be appropriate for all VE applications.

Figure 7 Closest concept - The Tilting Games Pad (Keytools)

CONCLUSION

As there were no devices identified through the technology review that met all the requirements of the design specification, it can be concluded that there is a need for the design and development of new concepts. Some exciting technology emerged from the virtual reality review, including the PINCH glove system and CAVE C04, see figure 8, which will help to inspire innovation in new concepts.



PINCH glove system (Fakespace)

CAVE C04 (Fakespace)

Figure 8 Inspiring technology from the virtual reality review

Future research

PRODUCE CONCEPT DESIGNS AND PROTOTYPES

The product design methods described by Baxter [14], for concept and prototype design, will be utilised for this stage of the design process. Initially, many concepts will be generated through employment of the concept generation methods, with reference to the design specification. Concept selection techniques will then be utilised to select the best concept against the design specification. Storyboards and sketches will be used to present concepts to the usability team and user group for modification and new idea generation. The selected concept(s) will go through embodiment design, which takes a concept and develops it to the point at which a full working prototype can be made. Finally, engineering drawings, which are the output from embodiment design, will be followed to produce the evaluation prototype(s).

CARRY OUT A USER-BASED ASSESSMENT

A user-based assessment of the prototype(s) will be carried out to evaluate the extent to which the user and organisational requirements have been met, and to recommend how the device(s) should be refined. The procedures, which will be followed, are described in the 'handbook of user-centred design' [10] and the 'usability engineering' section by Faulkner [9].

An evaluation plan will identify the resources required and the intended methodology, which will describe how the data will be collected. This planning also involves the preparation of a usability specification, which lists the usability attributes and usability metrics. The usability attributes define the success of the prototype(s), i.e. user-satisfaction, and the usability metrics determine how the attributes will be measured. A selected user group of students with moderate/severe learning difficulties will then use the prototype(s) to complete a pre-defined set of tasks within a VE. The results will be analysed and recommendations made to refine the prototype(s).

A process of evaluation, design refinement and re-evaluation will be carried out until the usability metrics, outlined in the usability specification have been attained. The completion of this study should result in the production of a VE interface device for young people with moderate/severe learning difficulties, which satisfies ISO 9241 (the British Standard giving guidance on usability).

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CONTROL OF VIRTUAL ENVIRONMENTS FOR PEOPLE WITH INTELLECTUAL DISABILITIES

Standen PJ, Lannen TL and Brown DJ

7. 1 Introduction

Computer based learning has enjoyed an increasing role in mainstream education with the development of more powerful personal computers available at a lower price. Computer delivered instruction has also started to make a contribution to the education of children with intellectual disabilities (eg Dube, Moniz & Gomes, 1995). It enables pupils to take charge of their own learning (Hawkridge & Vincent, 1992). Interactive software encourages active involvement in learning and gives the user the experience of control over the learning process (Pantelidis, 1993) and the learner can work at their own pace, attempting the same task over and over again, making as many mistakes as they like (Salem-Darrow, 1996).

The potential of a specific form of computer software, virtual environments (VE), for people with intellectual disabilities has been described by Cromby, Standen & Brown (1996). If used on a desk top system the public nature of the display permits interactions between the learner and a tutor or a peer. Cromby et al (1996) draw attention to three characteristics in addition to those shared with other forms of computer delivered education which make them particularly appropriate for people with intellectual disabilities. First, virtual environments create the opportunity for people with intellectual disabilities to learn by making mistakes but without suffering the real, humiliating or dangerous consequences of their errors. Secondly, virtual worlds can be manipulated in ways the real world cannot be perhaps providing less challenging versions of a task for the beginner. Thirdly, in virtual environments rules and abstract concepts can be conveyed without the use of language or other symbol systems which many people with intellectual disabilities often find difficult to acquire and use.

Initial work suggests that virtual environments are effective in facilitating the acquisition of living skills for example shopping and navigating new environments (Standen, Cromby & Brown, 1998) and Makaton sign Language (Standen & Low, 1996) by children with severe intellectual disabilities. With the wider availability of computers in both primary and secondary schools for mainstream and special education (Light, 1997) there is a need to investigate a range of questions about this new aid to learning. However at the same time, there are adults with intellectual disabilities who may have had little or no computer experience at school but whose continuing educational needs have been recognised by the Tomlinson Report (1997). This highlighted the need to provide courses that teach independent living and communication skills to people with intellectual disabilities.

Around 25 people in every thousand have mild or moderate intellectual disabilities and about four or five per thousand have severe intellectual disabilities (Department of Health, 2001). They are unlikely to enter employment when they leave school or to achieve the level of independence expected by the rest of society. Adults with intellectual disabilities will have the option to attend some form of college or day centre, the role of which is to provide training programmes relating to the development of daily living, social and educational skills.

7.2 The Barriers Created By Current Input Devices

To what extent can the use of virtual environments help in the development of these skills and through their improvement facilitate community inclusion for adults with intellectual disabilities? Brown, Neale, Cobb & Reynolds (1999) have developed a virtual city for people with intellectual disabilities to facilitate the learning of skills like catching a bus, road crossing and buying food in a café. However, in an early evaluation of the city Cobb, Neale & Reynolds (1998) found that in order to use the virtual city some individuals required considerable support to use the input devices. The joystick was used for navigation tasks and a standard two button mouse for interaction tasks as Hall (1993) had concluded that a joystick limited to two simultaneous degrees of freedom had the greatest utility in navigation. Brown, Kerr & Crosier (1997) evaluating a range of affordable and robust interaction and navigation devices also favoured use of the joystick finding it more suitable for navigation tasks than the keyboard and the mouse. For interaction tasks, the touch-screen and mouse were equally effective although the touch-screen was difficult to calibrate.

Many people with intellectual disabilities have fine motor difficulties as they suffer from conditions where damage has been caused to the central nervous system, such as cerebral palsy, multiple sclerosis, muscular dystrophy and dyspraxia. They therefore find the devices difficult to control. Brown, Kerr & Crosier (1997) concluded that future input device design or modification should ensure that they should be operable by people with fine motor difficulties, modifiable, robust, easy to calibrate and affordable. Until this access problem is solved, exploiting the benefits of virtual environments for this client group will be problematic. Lannen (1997) reviewed existing computer interface technology, including assistive computer access methods and virtual reality interfaces, to identify any existing devices, which with adaptation could provide a potential solution and to identify technological opportunities for satisfying the design requirements in novel ways. From reviewing assistive technology she identified head-tracking, eye-tracking and the foot mouse as having potential for people with fine-motor difficulties, yet none of these devices met all the requirements suggested by Brown et al (1997). The review of the virtual reality interfaces identified the 'position tracker' and 'motion platform' as having potential and these designs inspired the development of a prototype interactive device, the Mojo interactive seat. It meets some of the requirements suggested by Brown et al (1997) as it is operable by people with fine-motor difficulties, modifiable and affordable, see Figure 1.

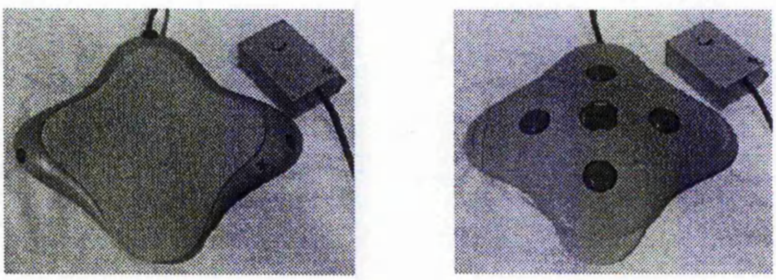

Figure 1. Mojo: an interactive seat for VE navigation

Mojo is a navigation device operable with gross motor movement. It consists of an interactive seat that is designed to enable people with intellectual and physical difficulties to explore virtual environments through movement of the lower body. For operation, the user sits on the device, which can be placed on a wheelchair seat, a chair or the floor. The user can then rock from side to side, forward and back onto the motion sensors, which transfer the user's movement to the virtual environment. The sensitivity of the product can be adjusted to suit the ability and weight of the user. This can allow very slight movements to be detected. Switches on each side of the device can be used to increase its degrees of freedom. Alternatively, external switches, which are more suited to the abilities of the user, can be plugged in to the device. Mojo was compared with a joystick for control of a VE navigation task by students with moderate to severe intellectual disabilities, some of whom were also physically impaired. From the results it was clear that less disorientation occurred when using Mojo than with the joystick, however, it would require considerable further refinement to provide an adequate solution to this human-VE interaction problem.

Soos (1998) developed a device based on a prototype hybrid wheelchair controller. This allowed direct manipulation of virtual environments by wheelchair users without intellectual disabilities. One of the main findings of this project was that users were already familiar with the operation of their wheelchair controller and it did not impose an extra cognitive load on them when attempting to navigate a virtual environment. This strategy of utilising the characteristics employed in familiar devices has many advantages in the design of input devices for people with intellectual disabilities.

Standen, Brown, Proctor and Horan (in press) used the virtual city to determine what strategies tutors employ in teaching people with intellectual disabilities to use virtual environments and how effective these are. Much of the time spent by the tutor in the learner's early sessions was on providing assistance with the input devices. Less time was given to help with the mouse than with the joystick but the first session had included specific training on using the mouse. Users experienced problems in remembering what tasks were accomplished by each device and in moving from one device to the other as many used the same (dominant) hand for both devices. This suggests that a single device would be easier to use. Whether one or two input devices are needed, corresponding to the tasks of navigation and interaction, it may also be the case that the same design may not suit everyone and that different versions of the product need to be produced.

7.3 The Nature Of The Difficulties With Existing Devices

Although several studies have now noted that these users experience difficulties with the input device which can be both frustrating and ultimately demotivating, the exact nature of the difficulties has not been documented. As a first step to producing a device for school aged students using virtual environments Lannen, Brown and Powell (in press) carried out a detailed analysis of the difficulties these users experienced using a joystick for navigation and a mouse for interaction. Seven male and seven female students aged between 7 and 19 years formed the user group. Two of the students had mild to moderate intellectual disabilities and the rest had severe intellectual disabilities. All had some degree of co-ordination, gross-motor or fine-motor difficulties. The VEs were displayed on a colour computer monitor and a standard 2-button mouse was used for interaction tasks. Initially, the Axys joystick (Suncom Technologies) was used for navigation tasks. However, as some of the students were experiencing difficulties in gripping the stick on this device, the last 4 students used the Wingman joystick (Logitech). The stick on the Wingman joystick is much taller and wider than the Axys joystick and is shaped to fit the hand, see figure 2.

Figure 2 The Wingman joystick (Logitech) & the Axys joystick (Suncom Technologies)

The students were asked to complete specified navigation and interaction tasks within the virtual factory, café or supermarket. Demonstrations of the devices and tasks were given before commencing the evaluations. Measures taken included misuse of the device (non-task related movement, harshness, pressing the wrong buttons, etc); support required (spoken instruction, physical assistance, etc); physical difficulties (insufficient strength, inability to grip properly, etc) and user comments and reactions.

Many of the difficulties users experienced were due to physical ability and device construction rather than to the user's understanding of how to use each device. For example, when using the joystick they frequently obtained too much left/right rotation, misused the button, had to have the base held still by the examiner and experienced grip difficulties with the mouse. The Wingman joystick was easier to grip than the Axys joystick, due to its size and shape, highlighting the importance of ergonomic design for increasing usability. Other difficulties appeared to be related to the user's level of cognitive understanding of how to use the devices for example, occurrence of random movement and frequent pressing of mouse buttons. To overcome these difficulties it may be necessary to gain a deeper knowledge of the users' cognitive and perceptual abilities, so that the devices can be refined to an appropriate level of understanding. Finally difficulties arose as a result of the design of the virtual environments which led to 12 students requiring physical help to complete some tasks. For example, one student required physical assistance with the Axys joystick to align his position in front of the exit doors in the virtual factory.

This evaluation highlighted the importance of considering the physical and cognitive abilities of the user group, as well as the tasks that the user must complete with the input devices, in order to develop a usable computer interface device. This theory is backed up by contemporary human-computer interaction (HCI) research, which also stresses that you should design for the user, the task and the environment (Faulkner, 1998). This point is also made by Newell and Cairns (1993) who highlight the fact that ergonomics research tends to be focussed on ordinary users with average abilities with designers using a single model of the user and making little attempt to specify the actual characteristics of the intended user group. They suggest that some system designers see themselves or their colleagues as archetypes of the system user. The conventional approach for including the consideration of the user, the task and the environment is the user-centred design process.

7.4 User-Centred Design

Usability is a crucial factor in the production of a successful human-computer interface and is central to the user-centred design process. The usability of a product is defined in ISO 9241, part 11 (1998) (the British Standard giving guidance on usability) as 'the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use'.

According to the ISO 13407 standard (1999) (human centred design processes for interactive systems) the key activities in user-centred design are:

1 Understand and specify the context of use
1 Specify the user and organisational requirements
2 Produce designs and prototypes
- Carry out a user-based assessment

When the consideration of people with disabilities is included in the design process it is usual to talk about "Design for all", "Universal Usability" or "Equitable Use" implying that the design should be useful and marketable to any group of users. However, Newell and Gregor (2000) consider that this ideal may be very difficult if not impossible to achieve. For example, different user groups may provide very conflicting requirements for a product. As an alternative, they propose a "User Sensitive Inclusive Design" which recognises that inclusivity is more achievable than a universal design. One of their conclusions is that "User Sensitive Inclusive Design needs to be an attitude of mind rather than simply mechanistically applying a set of 'design for all' guidelines. "

With this in mind, in our current research we are employing a methodology, outlined in Lannen, Brown and Powell (in press) which was determined by combining established guidelines on user-centred design eg INUSE (Daly-Jones, Bevan, and Thomas, 1999) and USERfit (Poulson, Ashby and Richardson, 1996, Poulson and Richardson, 1998; Poulson and Waddell, 2001) with contemporary human-computer interaction and product design research. This produces a five stage process.

7.4.1 Understand and Specify the Context of Use

This is achieved by conducting a Usability Context Analysis (UCA), which involves a user, task and environmental analysis. In Lannen et al (in press) this involved gathering information about each member of a group of 21 school aged students with intellectual disabilities, on the attributes that might affect the difficulties they experienced when using the input device. This information included their skills and knowledge, their physical, cognitive and perceptual abilities, communication, behaviour and motivations. The next step is an hierarchical task analysis, (Dix, Finlay, Abowd and Beale, 1998) which involves breaking down the primary tasks eg navigation tasks into subtasks eg "use input device to move to position in VE", which are further broken down eg "move forward", "move left". This analysis is used to determine the product design requirements, which are necessary to carry out each element of the main tasks. Finally the environment analysis involves an analysis of the organisational (eg will student be working alone), technical and physical factors (eg level of background noise) of the environment in which the product will be used. By gaining an understanding of these factors, a computer input device can be selected or developed to fit the task environment.

7.4.2 Specify The User and Organisational Requirements

This stage involves the usability team: a multi-disciplinary team which might include project advisors, a design engineer, human-computer interaction and special needs experts, a usability specialist a physiotherapist and an occupational therapist. The team considers the results of the first stage (UCA) translating them into design requirements. A Product Analysis is then conducted in order to describe how the design requirements could be met through specific device attributes. So for example, if the users experience slight hand tremor the device needs to be designed so that it will not detect unintentional movements. The final step in this stage is to collate the device attributes into a design specification which covers such categories as appearance and ergonomic design.

7.4.3 Technology Review

At this stage it is necessary to review existing technology to identify any computer interface devices that, with adaptation, could provide a potential solution and to identify opportunities for innovation. For the current design task the relevant areas would include virtual reality, assistive and general computer interface technology and gaming interface devices.

7.4.4 Produce Concept Designs and Prototypes

Baxter (1995) described methods for concept and prototype design. Initially, in conjunction with the usability team, many concepts may be generated with reference to the design specification. Concept selection techniques are then utilised to select the best concept against the design specification. Storyboards and sketches can be used to present concepts to the usability team and user group for modification and new idea generation. The selected concept(s) will go through embodiment design, which takes a concept and develops it to the point at which a full working prototype can be made. Finally, engineering drawings, which are the output from embodiment design, will be followed to produce the evaluation prototype(s).

7.4.5 Carry Out a User-Based Assessment

The prototype is then taken back to the user group to evaluate the extent to which the user and organisational requirements have been met, and to recommend how the device or devices should be refined (Faulkner, 1998). An evaluation plan will identify the resources required and the intended methodology, which will describe how the data will be collected. In our current study for example, we are using video recordings which are coded using a scheme established in an earlier study (Standen, Brown, Proctor and Horan, in press) This planning also involves the preparation of a usability specification, which lists the usability attributes and usability metrics. The usability attributes define the success of the prototype(s), i.e. user-satisfaction, misuse of devices. The usability metrics determine how the attributes will be measured for example, frequency of misuse as observed from video recordings. A selected user group then use the prototype(s) to complete a pre-defined set of tasks within a VE. The results are analysed and recommendations made to refine the prototype(s).

A process of evaluation, design refinement and re-evaluation is carried out until the usability metrics, outlined in the usability specification have been attained, see figure 3.

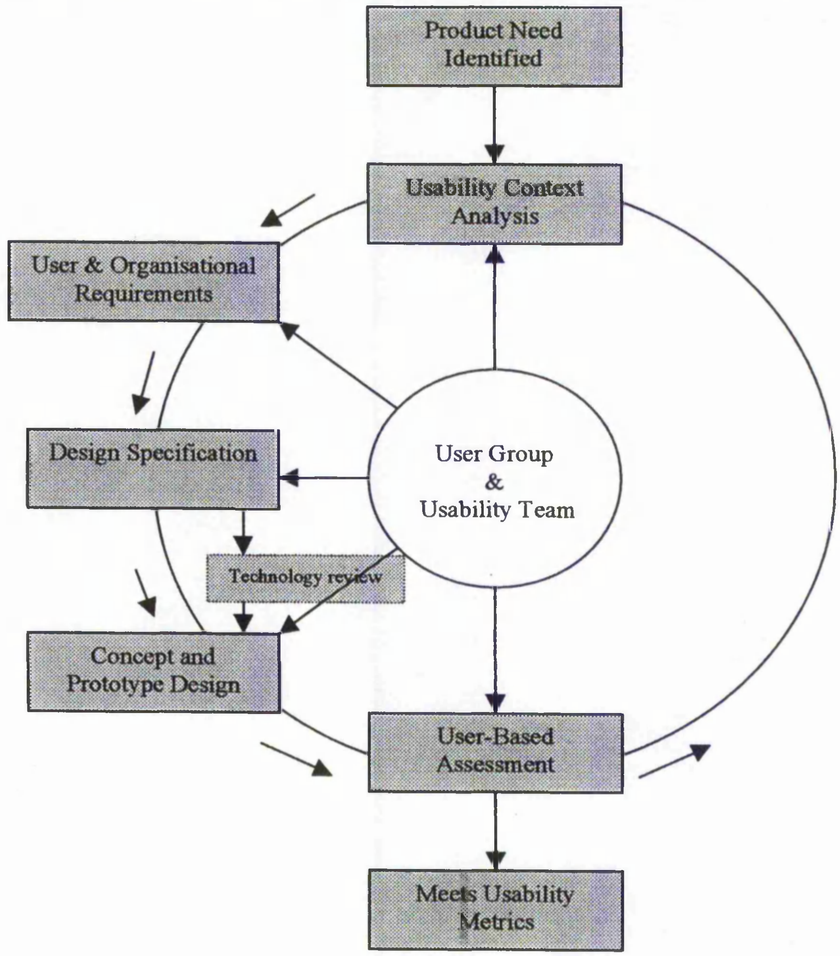

Figure 3 The user centred design cycle

7.5 Disability Focussed Design

This approach outlined above seeks to solve the problem of design for disability by involving users and specifying in detail their characteristics and the difficulties they experience with existing devices. A danger with this process is that it may reinforce the practice of considering the user population as falling into dichotomous groups: those with disabilities and those without, or in discrete groups: those without disabilities, those with gross motor disabilities, those with sensory impairments etc. This would suggest that design solutions have to be found for each group in turn and fall back on the solution where systems are designed exclusively for people with disabilities – the "orphan " products referred to by Newell and Gregor (2000). For us, a huge disadvantage of this solution is that the potential market for such a product might be too small to attract a manufacturer.

An alternative way of viewing design for disability is proposed by Newell & Cairns (1993) who believe that the consideration of the needs of extraordinary users can be a spur to a good product or system design for all. Using people with disabilities to evaluate products or systems can also highlight problems that would not have been obvious to those without such disabilities. They see disability as constituting a continuum not a dichotomy. On any given measure of human ability such as information processing, storage and recall of different types of data, expressive and receptive language, a range of values will be found in the population. At one end will lie those who are exceptionally good at this skill, at the other those who are less good. Everyone will possess this skill to a greater or lesser degree. Even people with obvious disabilities rarely have abilities that are different in quality from those of ordinary users, they are only an exaggeration or they lie on a different point on the continuum of human ability. These users simply have some functionalities that differ to some degree from the average. So, for example, it is rare for someone to have no motor control, most have more or less motor control relative to one another.

Additionally, Newell and Cairns (1993) remind us that abilities are not static but change with time. Accidents can cause temporary or permanent dysfunction. Disease and age cause substantial changes. In other words, a design solution for the less able will be a design solution for us all. They go on to report an example where technology originally designed to assist people with disabilities became widely used by the general public. Therefore able bodied people and mainstream researchers have benefited from developments designed for people with disabilities.

Newell and Cairns warned that if users are seen as two distinct groups, mainstream designers might develop too narrow a view of their user population. Presumably, the same argument could be used with designers for disability, especially if the adoption of a user-centred design process involves seeing the users with disabilities as categorically distinct from other users.

7.6 Conclusion

If Newell and Cairns are correct, then a solution to the control of virtual environments established using people with severe intellectual and physical disabilities, as well as being of benefit to the 3 per cent of the population with intellectual disabilities, may benefit others. Some of these beneficiaries might include those who experience motor difficulties, for example the increasing number of people with neuromuscular disorders especially those with strokes for whom virtual environments may have a rehabilitative or therapeutic role (Rose, Attree & Brookes, 1997). Additionally, the elderly who are unfamiliar with computer technology and groups with cognitive impairment might also benefit from a simpler input device. However, just as the remote control is now used by all able bodied people who wish to change their television channel without leaving their armchair, a virtual environment input device for people with intellectual disabilities may benefit a much wider group of users.

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Design of Virtual Environment Input Devices for People with Learning Disabilities – a User-Centred Approach

Tanja L Lannen, David J Brown and Heather M Powell

Department of Computing & Mathematics, the Nottingham Trent University, Burton Street, Nottingham, England

Contact: Tanja Lannen, tanja.lannen@hotmail.com, fax: (01253) 720570

Keywords: user-centred design, input device, virtual environment, learning disabilities

This paper describes the continuation of research introduced in a previous paper: 'Access to Virtual Learning Environments for People with Learning Difficulties', presented by the Authors at ICDVRAT 2000 in Sardinia. The research stems from the development of virtual environments (VEs) for people with learning disabilities and findings of usability difficulties with the computer input devices. For example, from an evaluation of VEs, developed to teach independent living skills to people with learning disabilities, it was found that individuals differed in the amount of support required to use the input devices; joystick for navigation and mouse for interaction (Cobb et al, 1998). It was also stated that navigation was found to be one of the most difficult tasks to do.

An evaluation has been carried out to identify the specific usability difficulties that are experienced in using the joystick and mouse to perform VE tasks (Lannen et al, 2000). This evaluation highlighted the importance of considering the physical and cognitive abilities of the user population, the tasks to be performed and the working environment, when selecting or designing a usable VE input system. This discovery led to the employment of a user-centred design (UCD) methodology to ascertain the specific requirements for the selection or design of a usable VE input system for people with learning disabilities.

According to the ISO 13407 European standard (Human-centred design processes for interactive systems, 1999) the key activities in UCD are:

- Understand and specify the context of use
- Specify the user and organisational requirements
- Produce designs and prototypes
- Carry out a user-based assessment

The first stage, 'understand and specify the context of use', was achieved by conducting a Usability Context Analysis (UCA), which included an analysis of the user population, task and working environment. The results of the user analysis were described in the preceding paper (Lannen et al, 2000). A synopsis of the results from the UCA and their influence on the subsequent stage of the methodology will be covered in this paper, before focusing on concept designs, prototypes and the user-based assessment. The aforementioned synopsis will include a description of the product design specification, which lists the specific input device requirements.

A technology review was conducted, before proceeding to concept design, to identify any existing computer input devices that satisfied the device requirements. As no devices were found to meet a sufficient number of these requirements, it was concluded necessary to design and develop new concepts.

Established product design methods were utilised for the design and prototyping stage of the UCD process (Baxter et al, 1995). Many concepts were generated through the employment of concept generation methods, which were guided by the design specification. A concept selection matrix was then used to select the best concept against the device requirements. The chosen concept proceeded through embodiment design, which involved aesthetic and ergonomic design; mechanical, electronic and computer systems design; materials research and 3D computer modelling. The embodiment design stage resulted in the production of engineering drawings, from which a working prototype was manufactured.

The objectives of the user-based assessment were to evaluate the usability of the new VE input system, ascertain whether a UCD methodology is a successful approach and to identify the next research step, i.e. device refinement. A control and an experimental condition were utilised in the evaluation:

- Control condition – 14 subjects with severe learning disabilities were observed using the joystick/mouse to control VE tasks
- Experimental condition – 14 subjects with severe learning disabilities were observed using the new computer input system to control VE tasks

This experimental design allowed the objective 'ascertain whether a UCD methodology is a successful approach' to be tested. A usability specification was constructed using the Guiding Principles of usability, which are stated in the ISO 9241-9 European standard (requirements for non-keyboard input devices, 2000). This specification, which lists the usability factors and how they will be measured, was used to guide each evaluation. Where appropriate, a rating scale was devised for each measure to enable the statistical analysis of the data. For example, the measure 'initial test' was given the following rating scale: 1 = can't use; 2 = use 1 function; 3 = use some functions; 4 = can use; 5 = can use well.

The final part of this paper covers the results and conclusions of the user-based assessment and the future development of the research. An EPSRC research grant has been awarded based on this research, to continue to explore the design and development of VE input devices for people with learning disabilities.

References

M Baxter (1995), Product design: practical methods for the systematic development of new products, Chapman & Hall, London.

S V G Cobb, H R Neale and H Reynolds (1998), Evaluation of virtual learning environments, Proc. ECDVRAT, Skovde, Sweden, pp. 17-23.

T L Lannen, D J Brown and H M Powell (2000), Access to virtual learning environments for people with learning difficulties, Proc. ICDVRAT, Alghero, Sardinia.

Presentation requirements:
PowerPoint presentation and video of new input device in use (VHS)

Appendix B

- Assessment Measurement Tables (completed examples)

Examples of Assessment Measurement Table

Student 1:

USER NAME / AGE	INPUT DEVICE	DATE
1	Axys joystick & mouse	18.02.00

Assessment measures	Yes / No	Comments
Misuse of Device		
Non-task related movement	Yes	Quite a lot of random movement of both devices.
Harshness	Yes	Random movement of the stick, quite aggressive. Not gentle. Moving mouse back and forth.
Pressing wrong buttons	Yes	Pressing joystick button. Repeatedly pressing the mouse button.
Other	Yes	Trying to use the joystick for interaction.
Support required		
Spoken instruction	Yes	Frequent prompting for interaction and navigation.
Physical assistance	Yes	Physical guidance and movement of the mouse cursor into position.
Doing complete task	No	The evaluator almost did complete task, entering factory.
Other	Yes	Demonstration of device and tasks.
Physical ability		
Sufficient strength	Yes	Sufficient strength, but not channelling it in the right way.
Able to grip properly	No	Her grip is a bit tight on the stick, not relaxed.
Any other points		
Workplace		
Able to reach	Yes	Able to reach both devices.
Any other points	Yes	THe workstation could be more comfortable and help to engage the user on the task.
Attention		
On task	Yes	She focused on the screen quite a lot.
On device	Yes	She looked at both devices when finding them or using them.
On other	Yes	Occasionally looked at the evaluator.

User comments / reactions	
Positive	Negative

Showed some excitement and interest. Pointed at some things on the screen.	Didn't always respond to spoken instruction.
User Satisfaction	
Was quite content throughout the experience. Showed some excitement and interest.	
Any other details	
She has used the virtual café before, she has used the devices before. She would need more time to learn to use them. It would be better for her if the devices were more simple and obvious how to use. The virtual factory is probably not age appropriate for her. A simple world, to get used to VEs could be good for her.	
Time taken to complete task	

Student 2:

USER NAME / AGE	INPUT DEVICE	DATE
2	Axys joystick & mouse	18.02.00

Assessment measures	Yes / No	Comments
Misuse of Device		
Non-task related movement	Yes	Some random movement of both devices. More interested in moving stick about and watching movement in world, than trying to do the task.
Harshness	No	He is quite firm with both devices, but not destructive.
Pressing wrong buttons	Yes	Pressed joystick button. Pressing right mouse button instead of left. Pressing the mouse button repeatedly.
Other	No	
Support required		
Spoken instruction	Yes	Frequent prompting for interaction and navigation.
Physical assistance	Yes	Physical guidance of joystick and movement of the mouse cursor into position.
Doing complete task	No	
Other	Yes	Demonstration of device and tasks.
Physical ability		
Sufficient strength	Yes	Sufficient strength, but not channelling it in the right way.
Able to grip properly	No	Not a comfortable grip. Looks quite awkward.
Any other points		

Workplace		
Able to reach	Yes	He was just able to reach. The desk could be lower to help him.
Any other points	Yes	He fidgets with the devices and moves about on his seat. The workstation could be more comfortable.
Attention		
On task	Yes	He looked at the screen quite a lot.
On device	Yes	He looked at the devices when finding them.
On other	Yes	He was only distracted a little to look at [illegible] who was also present at the evaluation.

User comments / reactions	
Positive Lots of excitement shown. More excited about the café than the factory. Wanted to have another go. Pointed at things on the screen.	Negative A little annoyed when evaluator wants to demonstrate, he just wants to use it.
User Satisfaction	
Very happy and smiley throughout the evaluation.	
Any other details	
Not used the VEs before. Seemed to enjoy them. Not used the devices before, would require more practice with both devices. Understood that mouse was for interaction and joystick for navigation, but the devices were not obvious to him how to use. Buttons need to be difficult to access when not required. A training environment would be good for him, to get used to the devices and VEs. He does seem to enjoy using computers as wanted to have a go on the other computer after the evaluation.	
Time taken to complete task	

Student 3:

USER NAME / AGE	INPUT DEVICE	DATE
3	Axys joystick & mouse	16.02.00

Assessment measures	Yes / No	Comments
Misuse of Device		
Non-task related movement	No	There was some slight random movement, but she was trying to do the task.
Harshness	No	She was quite gentle with the devices.
Pressing wrong buttons	No	She avoided pressing the joystick button.
Other	Yes	Using it in different ways, which is unnecessary.

Support required		
Spoken instruction	Yes	Frequent prompting to do navigation and interaction tasks.
Physical assistance	Yes	Required some physical assistance with the initial tasks. Less required as session went on.
Doing complete task	No	
Other	Yes	Encouragement, to keep going.
Physical ability		
Sufficient strength	Yes	
Able to grip properly	No	Kept altering her grip on the joystick. Mouse gripping was fine.
Any other points	Yes	Unsure of her visual ability.
Workplace		
Able to reach	Yes	No problems with reaching the devices.
Any other points	Yes	Workplace design could be more suited to system. An integrated workstation.
Attention		
On task	Yes	Quite good attention on task, but would stop after each task and require prompting for next. Would sit back and smile at the tester.
On device	Yes	Some attention on the devices, when switching from one to the other and when concentrating on the joystick.
On other	No	

User comments / reactions	
Positive Smiling, laughing.	Negative
User Satisfaction	
Very content throughout the evaluation. Appeared less enthused by the end. The world could perhaps be more interesting for her.	
Any other details	
She is not fully engaged in the task. If left to use the system on her own, I'm not sure she would do much. Used VEs, joystick and mouse before. Understood that joystick was for navigation and mouse for interaction. Needs a world she can do by herself and one which interests her. A confidence building world (training), which starts off quite simple and gets progressively more difficult.	
Time taken to complete task	

Student 4:

USER NAME / AGE	INPUT DEVICE	DATE
4	Wingman joystick & mouse	18.02.00

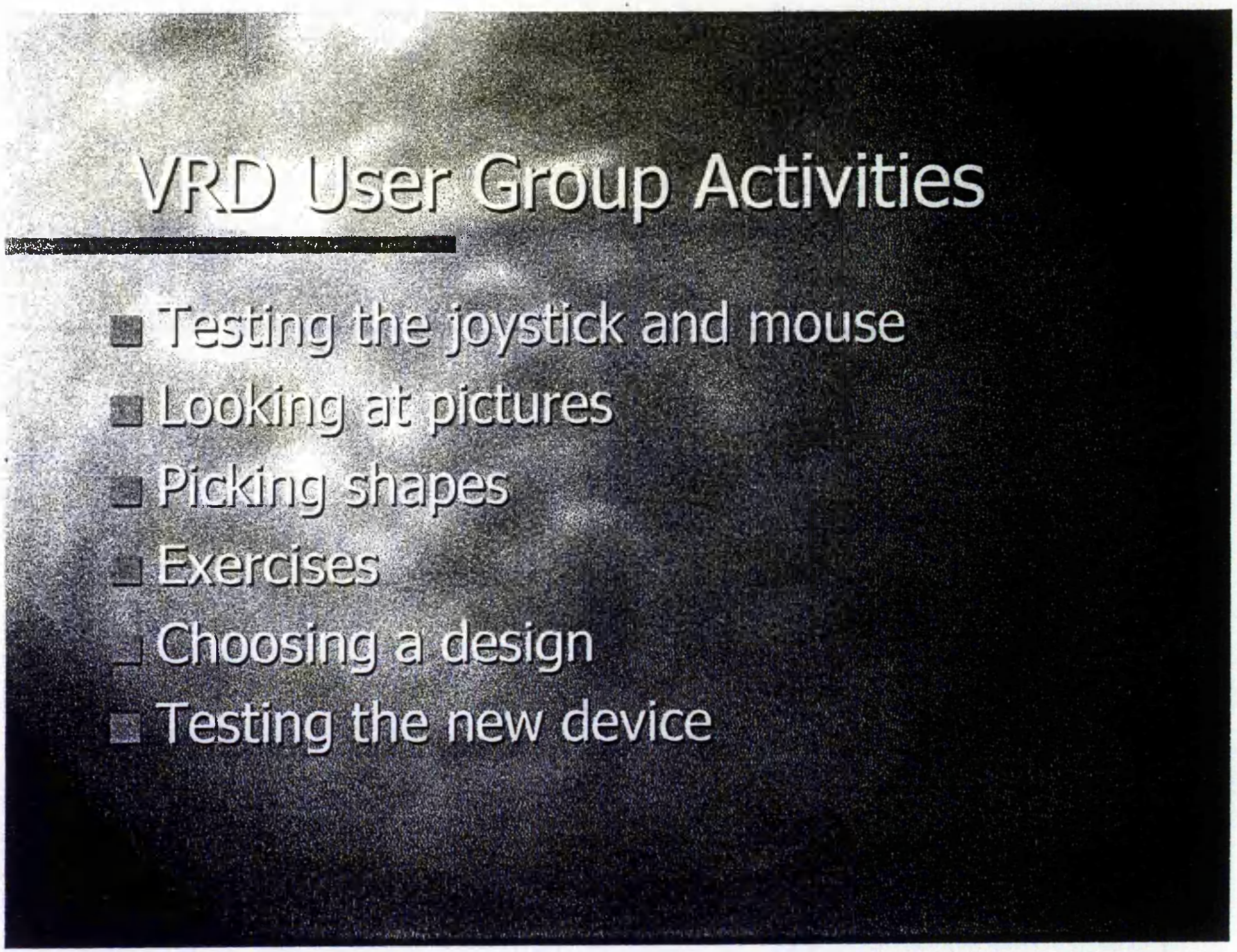
Assessment measures	Yes / No	Comments
Misuse of Device		
Non-task related movement	Yes	A lot of random movement. A lot of spinning. Not really trying to do the task.
Harshness	Yes	Quite aggressive with the joystick. Moving the stick quickly and fully in each direction. Uncontrolled movement of mouse. Pressing the button quite hard.
Pressing wrong buttons	Yes	Pressing the joystick button a lot.
Other	Yes	Trying to use the joystick for interaction tasks.
Support required		
Spoken instruction	Yes	Frequent prompting for interaction and navigation.
Physical assistance	Yes	Required a lot of navigation assistance. Also assistance to move mouse cursor into position. The evaluator held the base of the joystick to steady it.
Doing complete task	Yes	The evaluator did some navigation tasks in the factory.
Other	Yes	Demonstration of devices and tasks.
Physical ability		
Sufficient strength	Yes	Sufficient strength, but not channelling it in the right way.
Able to grip properly	No	Gripping the joystick a bit far up and not avoiding pressing the button. Wingman joystick about the right size for him. Able to grip the mouse properly.
Any other points	Yes	Has a lot of strength. Appears to have some co-ordination difficulties.
Workplace		
Able to reach	Yes	Able to reach the devices easily.
Any other points	Yes	The workstation could be more comfortable. Could the workstation help to immerse him in the task.
Attention		
On task	Yes	Looked at the screen a bit, but not fully attentive to task.
On device	Yes	Occasionally looking at the devices when using them. Looking at devices when reaching for them.
On other	Yes	Looking at the evaluator.

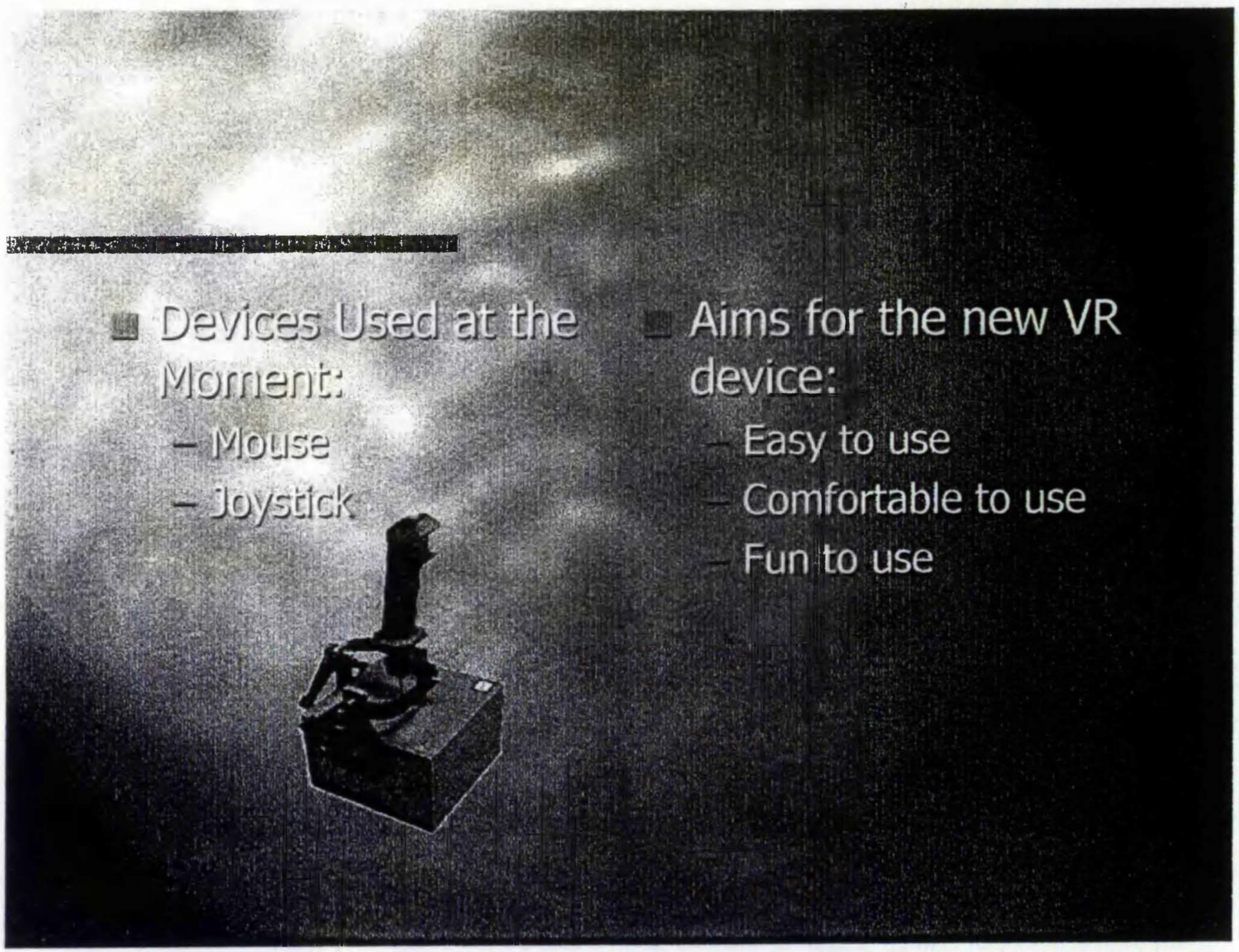
User comments / reactions	
Positive A bit of laughing, a little smiling.	Negative Frustration with tasks. Sitting back, not focusing on task. He said he was bored.
User Satisfaction	
Didn't appear to be very content throughout the session. He said he was bored. Could this have been due to the difficulties he was having.	
Any other details	
Had used the VEs and devices before. He may have been bored because he was using the same VEs again. More exciting worlds would be good to try with him, to see if they can improve his engagement.	
Time taken to complete task	

Appendix C

- VRD (Virtual Reality Device) user group presentation – overhead projector slides


Design of a New
Virtual Reality Device
With help from pupils at the
Shepherd School, Nottinghamshire


VRD User Group Activities
Testing the joystick and mouse
Looking at pictures
Picking shapes
Exercises
Choosing a design
Testing the new device


Devices Used at the Moment:
– Mouse
– Joystick
Aims for the new VR device:
– Easy to use
– Comfortable to use
– Fun to use


VRD User Group Party
Today we are having a party to:
– thank you all for your help with the project
– meet all the people in the VRD User Group
– to have a good time

Appendix D

- BPVS-II results
- MAT-SF results
- QNST-II results
- QNST-II tasks

BPVS-II RESULTS

Table 1. BPVS-II Raw Scores (RS), Standardised Scores (SS) and Score Range

User	Age	Gender	RS	SS	SS-6	SS+6	Score range
A	8:04	F	45	68	62	74	ELS-MLS
B	10:07	F	31	40-	33	45	ELS
C	11:07	F	40	41	35	47	ELS
D	7:03	M	30	63	57	69	ELS
E	8:04	M	31	54	48	60	ELS
F	9:03	M	16	40-	33	45	ELS
G	12:10	F	58	50	44	56	ELS
H	14:10	F	35	40-	33	45	ELS
I	15:07	F	79	51	45	57	ELS
J	15:00	M	55	40-	33	45	ELS
K	15:02	M	58	40-	33	45	ELS
L	15:03	M	48	40-	33	45	ELS
M	16:04	M	62	40-	33	45	ELS
N	17:04	F	68	42	36	48	ELS
O	18:10	F	30	40-	33	45	ELS
P	18:11	F	48	40-	33	45	ELS
Q	16:11	M	96	64	58	70	ELS-MLS
R	17:08	M	40	40-	33	45	ELS
S	18:00	M	74	47	41	53	ELS
T	18:09	M	65	40	34	46	ELS
U	19:03	M	34	40-	33	45	ELS
V	19:04	M	13	40-	33	45	ELS

Details of Results:

- Raw score (RS): the score achieved on the test
- Standardised Score (SS): found by checking the raw score with the norm table provided with the test
- Confidence Band (CB): this test uses a 68% confidence band, which means we can be sure that a person's true score lies within the limits indicated
- SS-6 to SS+6: this is how the 68% confidence band is found for the standardised score
- Percentile Rank (PR): the percentile rank indicates the percentage of people who obtain a standardised score equal to or below that of the subject
- Highlighted (shaded) scores: the students who obtained these scores were eliminated from the study, due to extremely low scoring compared with the rest of the user group

Table 2. BPVS-II Raw Scores (RS), Age Equivalent (AE) and Percentile Ranks (PR)

User	Age	Gender	RS	AE	AE-CB	PR	PR-CB
A	8:04	F	45	4:04	3:10 – 5:01	2	1 to 4
B	10:07	F	31	3:02	2:08 – 3:06	\	\
C	11:07	F	40	3:09	3:03 – 4:05	\	\
D	7:03	M	30	3:02	2:08 – 3:06	1	1- to 2
E	8:04	M	31	3:02	2:08 – 3:06	\	\
F	9:03	M	16	2:05	2:00 – 2:09	\	\
G	12:10	F	58	5:08	5:02 – 5:05	\	\
H	14:10	F	35	3:05	2:10 – 3:10	\	\
I	15:07	F	79	7:09	7:02 – 8:04	\	\
J	15:00	M	55	5:05	4:10 – 6:01	\	\
K	15:02	M	58	5:08	5:02 – 6:05	\	\
L	15:03	M	48	4:08	4:02 – 5:04	\	\
M	16:04	M	62	6:01	5:07 – 6:10	\	\
N	17:04	F	68	6:08	6:01 – 7:04	\	\
O	18:10	F	30	3:02	2:08 – 3:06	\	\
P	18:11	F	48	4:08	4:02 – 5:04	\	\
Q	16:11	M	96	9:10	8:10 – 10:09	1	1- to 2
R	17:08	M	40	3:09	3:03 – 4:05	\	\
S	18:00	M	74	7:03	6:08 – 7:11	\	\
T	18:09	M	65	6:05	5:10 – 7:01	\	\
U	19:03	M	34	3:04	2:10 – 3:08	\	\
V	19:04	M	13	2:04	2:00 – 2:08	\	\

MAT-SF RESULTS

Table 1. MAT-SF Raw Scores (RS), Age Equivalent (AE) and Stanine Scores (S)

User	Age	Gender	RS	AE	AE-CB	S	S-CB
A	8:06	F	9	6:08	5:11 – 7:02	3	3 - 3
B	10:09	F	5	5:00	<5:00 – 5:11	1	1 - 1
C	11:09	F	6	5:06	<5:00 – 6:04	1	1 - 1
D	7:05	M	10	6:11	6:04 – 7:04	5	4 - 6
E	8:06	M	5	5:00	<5:00 – 5:11	2	1 - 3
G	13:01	F	11	7:02	6:08 – 7:06	1	1 - 1
H	15:01	F	1	<5:00	<5:00 - <5:00	1	\ - 1
I	15:09	F	8	6:04	5:06 – 6:11	1	1 - 1
J	15:02	M	13	7:06	7:02 – 8:03	1	1 - 1
K	15:05	M	8	6:04	5:06 – 6:11	1	1 - 1
L	15:05	M	10	6:11	6:04 – 7:04	1	1 - 1
W	16:01	M	9	6:08	5:11 – 7:02	1	1 - 1
M	16:06	M	10	6:11	6:04 – 7:04	1	1 - 1
N	17:06	F	9	6:08	5:11 – 7:02	1	1 - 1
O	19:00	F	7	5:11	5:00 – 6:08	1	1 - 1
P	19:01	F	8	6:04	5:06 – 6:11	1	1 - 1
Q	17:01	M	11	7:02	6:08 – 7:06	1	1 - 1
R	17:10	M	1	<5:00	<5:00 - <5:00	1	\ - 1
S	18:02	M	8	6:04	5:06 – 6:11	1	1 - 1
T	18:11	M	7	5:11	5:00 – 6:08	1	1 - 1
U	19:02	M	3	<5:00	<5:00 - 5:00	1	1 - 1

Details of Results:

- Raw Score (RS): the score achieved on the test
- Confidence Band (CB): this test uses a 68% confidence band, which means we can be sure that a person's true score lies within the limits indicated
- Stanine Score: stanines divide the normal distribution into 9 units, see table 2
- Percentile Rank (PR): the percentile rank indicates the percentage of people who obtain a standardised score equal to or below that of the subject

Table 2. Interpretation of Stanine Scores

Stanine	Stanine Description
1	At high risk of academic failure
2	At risk of academic failure
3	Academic problems are possible
4	Low average
5	Average
6	High average
7	Academic success is likely
8	Superior
9	Very superior

Table 3. MAT-SF Raw Scores (RS) and Percentile Ranks (PR)

User	Age	Gender	RS	RS-CB	PR	PR-CB
A	8:06	F	9	7 - 11	19	13 - 23
B	10:09	F	5	3 - 7	1	1 - 3
C	11:09	F	6	4 - 8	1	1 - 2
D	7:05	M	10	8 - 12	50	38 - 60
E	8:06	M	5	3 - 7	5	1 - 13
G	13:01	F	11	9 - 13	2	1 - 2
H	15:01	F	1	-1 - 3	1	\ - 1
I	15:09	F	8	6 - 10	1	1 - 1
J	15:02	M	13	11 - 15	1	1 - 2
K	15:05	M	8	6 - 10	1	1 - 1
L	15:05	M	10	8 - 12	1	1 - 1
W	16:01	M	9	7 - 11	1	1 - 1
M	16:06	M	10	8 - 12	1	1 - 1
N	17:06	F	9	7 - 11	1	1 - 1
O	19:00	F	7	5 - 9	1	1 - 1
P	19:01	F	8	6 - 10	1	1 - 1
Q	17:01	M	11	9 - 13	1	1 - 1
R	17:10	M	1	-1 - 3	1	\ - 1
S	18:02	M	8	6 - 10	1	1 - 1
T	18:11	M	7	5 - 9	1	1 - 1
U	19:06	M	3	1 - 5	1	1 - 1

QNST-II RESULTS

User	Age	Sex	Subtest	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Tot score
A	8:06	F	Score	2	5	5	4	7	2	1	-	2	2	6	2	1	2	2	43
			Category	MD	MD	MD	MD	MD	MD	NR	-	MD	NR	MD	MD	NR	MD	MD	MD
B	10:08	F	Score	2	6	8	4	8	2	5	-	2	3	10	2	-	3	2	57
			Category	MD	SD	SD	MD	MD	MD	MD	-	MD	MD	SD	MD	-	MD	MD	SD
C	11:08	F	Score	1	6	8	3	8	2	2	-	2	0	6	2	1	3	2	46
			Category	NR	SD	SD	NR	MD	MD	NR	-	MD	NR	MD	MD	NR	MD	MD	MD
D	7:04	M	Score	2	2	5	-	6	-	1	-	2	-	-	-	-	0	1	19 +
			Category	MD	MD	MD	-	MD	-	NR	-	MD	-	-	-	-	NR	NR	MD
E	8:06	M	Score	2	6	6	1	7	3	4	-	5	0	2	2	-	3	2	43
			Category	MD	SD	MD	NR	MD	MD	MD	-	SD	NR	NR	MD	-	MD	MD	MD
G	13:00	F	Score	3	9	4	1	7	2	3	-	3	-	-	-	-	0	0	32 +
			Category	MD	SD	MD	NR	MD	MD	MD	-	MD	-	-	-	-	NR	NR	MD
H	15:00	F	Score	2	5	4	6	5	3	4	-	3	-	4	2	2	0	1	41
			Category	MD	MD	MD	MD	NR	MD	MD	-	MD	-	MD	MD	MD	NR	NR	MD
I	15:08	F	Score	2	5	1	2	7	2	1	-	1	1	3	1	0	1	0	27
			Category	MD	MD	NR	NR	MD	MD	NR	-	MD	MD	NR	NR	NR	NR	NR	MD
J	15:01	M	Score	1	4	5	1	6	2	2	-	2	1	1	1	1	3	1	31
			Category	NR	MD	MD	NR	MD	MD	NR	-	MD	NR	NR	NR	NR	MD	NR	MD
K	15:04	M	Score	2	3	7	1	6	2	4	-	1	3	3	2	2	2	1	39
			Category	MD	MD	SD	NR	MD	MD	MD	-	MD	MD	NR	MD	MD	MD	NR	MD
L	15:04	M	Score	1	2	6	3	7	2	4	-	2	1	8	2	2	0	0	40
			Category	NR	MD	MD	NR	MD	MD	MD	-	MD	NR	SD	MD	MD	NR	NR	MD
W	16:00	M	Score	1	1	0	0	8	1	3	-	4	0	7	2	2	3	1	33
			Category	NR	NR	NR	NR	MD	NR	NR	-	SD	NR	SD	MD	MD	MD	NR	MD
M	16:05	M	Score	1	5	2	4	8	3	2	-	1	1	3	3	1	2	1	34
			Category	NR	MD	NR	MD	MD	MD	NR	-	MD	NR	NR	SD	NR	MD	NR	MD

User	Age	Sex	Subtest	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Tot score
N	17:05	F	Score	1	1	1	10	7	3	1	0	4	-	6	3	-	3	0	40
			Category	NR	NR	NR	SD	MD	MD	NR	NR	SD	-	MD	SD	-	MD	NR	MD
O	18:11	F	Score	2	5	6	1	5	2	4	1	5	3	7	3	2	2	0	48
			Category	MD	MD	MD	NR	NR	MD	MD	MD	MD	SD	MD	SD	MD	MD	NR	MD
P	19:00	F	Score	1	6	5	1	4	3	4	-	1	3	3	1	1	3	0	36
			Category	NR	SD	MD	NR	NR	MD	MD	-	MD	MD	NR	NR	NR	MD	NR	MD
Q	17:01	M	Score	2	6	7	1	4	4	2	0	5	3	3	3	-	3	2	45
			Category	MD	SD	SD	NR	NR	SD	NR	NR	SD	MD	NR	SD	-	MD	MD	MD
R	17:10	M	Score	1	4	0	6	5	3	1	-	5	3	4	2	-	2	1	37
			Category	NR	MD	NR	MD	NR	MD	NR	-	SD	MD	MD	MD	-	MD	NR	MD
S	18:02	M	Score	1	5	5	-	3	-	3	-	2	-	0	0	-	1	1	21 +
			Category	NR	MD	MD	-	NR	-	NR	-	MD	-	NR	NR	-	NR	NR	MD
T	18:11	M	Score	0	5	5	6	4	-	4	-	5	-	3	3	-	2	2	39
			Category	NR	MD	MD	MD	NR	-	MD	-	SD	-	NR	SD	-	MD	MD	MD
U	19:05	M	Score	3	6	7	1	4	-	4	-	5	6	-	-	-	2	1	39 +
			Category	MD	SD	SD	NR	NR	-	MD	-	SD	MD	-	-	-	MD	NR	MD

Details of Results:

- Under each subtest are relevant tasks to which a weighted score is assigned
- For each subtest the task scores are added, then the sum of all 15 subtests is computed
- The total score is categorised as indicating a severe discrepancy from the normal range of function (SD), moderate discrepancy (MD) or normal range (NR) of function

QNST-II Tasks

Note: E = examiner; S = subject

1. Hand Skill
- Use a pen to write name
- Use a pen to write a sentence

2. Figure Recognition and Production
- Name and draw the five geometric figures

3. Palm Form Recognition
- S is asked to identify, solely by touch, numerals drawn on the palm of the hand
- If S has failed to recognise more than half the numerals, E should then present the easily recognised and frequently used letters suggested in the protocol

4. Eye Tracking
- Note: if there is any known sight deprivation or if S is legally blind, this subtest should not be administered
- E holds a pencil at S's eye level and asks S to follow it as it is moved back and forth
- E moves the pencil up and down four times

5. Sound Patterns
- Note: if there is any known hearing loss, this subtest should not be administered
- S is asked to reproduce sound patterns, by patting hands on knees, after they are demonstrated
- S is asked to reproduce the same sound patterns orally, using the syllables *dot dot*, after they are demonstrated

6. Finger to Nose
- Note: Before beginning, E holds up his right hand with the index finger extended and asks S to "Hold up this finger." (E must make no mention of right or left, as this is a check of left-right discrimination.)
- S is asked to close both eyes and reach back and forth between E's hand and the tip of his own nose.

7. Thumb and Finger Circle
- Note 1: for all motor tasks, it is important to note whether S's performance improves with practice or whether S tires easily and performance deteriorates
- S is asked to perform successive circles by touching the thumb to each of the fingers in sequence, starting with the right forefinger and ending with the little finger.

8. Double Simultaneous Stimulation of Hand and Cheek
- E observes whether S is able to feel a gentle touch on the hand at the same time as his cheek is touched

9. Rapidly Reversing Repetitive Hand Movements
- E demonstrates by placing hands on thighs, palms down, with fingers close together. E then turns both his hands over simultaneously. E continues turning his hands over, slowly at first and then rapidly accelerating
- S does what E has demonstrated

10. Arm and Leg Extension

- S is seated with arms and legs extended in front of him (It is important for S to spread his fingers as wide as possible). Check arms and calves for motor tone. Touch fingertips lightly to check for tremor.

11. Tandem Walk
- S has his eyes open and walks in a straight line for at least 10 feet, placing the heel of each shoe directly against the toes of the opposite foot
- S walks backward on the line, heal-to-toe
- S repeats the tandem walk forward with eyes closed

12. Stand on One Leg
- S is asked to balance himself with eyes open, first on one foot, then on the other, for a count of 10 each time
- If S does well on both right and left with eyes open, S is asked to repeat the task with eyes closed

13. Skip
- S is asked to skip across the room (to older boys: "Try hopping on one foot and then the other. In other words, do a skip like boxers do"). Observe how S follows directions and balances.

14. Left-right Discrimination
- This section is scored using performances from three other subtests (6, 7 and 12). If S responds on any of these tasks as if looking in a mirror, that response is developmentally immature.

15. Behavioural Irregularities
- This final item is derived by general observations of S's behaviours during the entire test session.

Appendix E

- Range of Movement (ROM) test
- Teacher Questionnaire

Range of Movement test (ROM test)

Table 1. Upper extremity range of movement

Upper Extremity	Comments
Shoulder (L)	
Shoulder (R)	
Elbow (L)	
Elbow (R)	
Wrist (L)	
Wrist (R)	
Fingers (L)	
Fingers (R)	

* R = right and L = left

Table 2. Ability to reach

Reach	Comments
Left hand/ left bang	
Left hand/ right bang	
Right hand/ right bang	
Right hand/ left bang	
Middle	

Table 3. Test methods

Methods for upper extremity tests
• Shoulder: throw and catch a ball • Elbow: wave from elbow; lift a weight action • Wrist: wave from wrist; bend hands forward and backward • Fingers: Press buttons • Reach: bang saucepan with wooden spoon

Questionnaire (for teachers)

The Virtual Environment (VE) System

VE system: includes a computer monitor and hard drive, input device(s) and virtual environment software

I would appreciate if you could answer the questions in the table below, thank you

On computer work, is it better for pupils to work alone or in small groups? (If small groups, how many in a group?)
If a virtual environment system was available, where would you prefer it to be used? ▪ In the class room ▪ In a room other than the classroom (specify which room, if possible)
If the VE system was used in the classroom, how much teacher/carer assistance would be available?
If the VE system was used in a room other than the classroom, how much teacher/carer assistance would be available?
How often do the pupils in your class use computers?
Is there a specific time allocated in your pupils' timetable for using computers?
What skills would it be useful to teach using a virtual environment system?
What is the average attention span of the pupils in your classroom?
Would it be beneficial for the pupils to include Makaton symbols on the input device or in the software?

Appendix F

- Context Report
  - Section 1: user analysis
  - Section 2: task analysis
  - Section 3: environment analysis

- Specific user characteristics (D, E, H)

Context Report

Section 1. User analysis

1.1 User Types	
a) User types identified	Primary Product User: - School pupils with learning difficulties Secondary Users - Teachers, support staff, technical staff, and parents/carers
b) User types for Usability Evaluation	Primary Users - school pupils with learning difficulties
c) User Group	Size of group: 21 (5 primary, 8 senior and 8 from 16+) Age range: 7:05 to 19:00 Gender: 9 female and 12 male Syndromes - Downs Syndrome: 5 - Microcephalic: 4 - Stickler Syndrome: 1 - Cri-du-chat: 1 - Williams Syndrome: 1 - Brain damage: 1 - CP in both legs and right arm Medical - Epileptic: 3 - Serious heart condition: 1 - Hypotonic: 1 - Mild jaundice: 1 - Autistic tendencies: 1
1.2 Skills & Knowledge	
a) Input devices	Can use switches: 21 Can use a touch-screen: 19 (2 with motor control difficulty) Good joystick control: 9 Joystick difficulty: 9 cognition, 3 motor Good mouse control: 10 Mouse difficulty: 8 cognition, 3 motor Limited keyboard use: 12 Copy types (keyboard), needs capitals: 5 Copy types with easy: 1
b) VR Experience	Used VEs before: 6
c) Computer experience	Can switch on computer and load a program: 4 Can load a program: 3 Learning cause and effect: 1 Enjoy using the computer: most students
d) Attainments	Remembers sequences of activities: 9 Read his/her name and classmates: 10 Completes reading workbooks: 4 Good understanding of addition and subtraction: 5 Does simple probability work: 1 Understands function of money: 5 Understands time (1/2, ¼ pas): 5 Good cognition of shapes: 7 Copy write: 7 Attempts to form written words: 5

1.3 User Attributes	
a) Physical abilities	**Gross-Motor** Good gross-motor ability - Independently mobile: 20 - Good upper extremity movement: 11 - Good reach ability: 15 Gross-motor difficulties - Unsteady gate: 3 - Tires quickly when walking: 3 - Uses a walker: 1 - Uses Lecky Chair & Major Buggy: 1 - Unsteady arm movement: 2 - Tense arm: 1 - Can't fully stretch right arm: 1 - Trunk strength: 2 - Weight bearing in arms: 2 - Co-ordination: 14 - Motor planning: 18 - Body symmetry: 14 - Balance: 16 **Fine-Motor** Good fine-motor ability - Good pen grip: 11 - Can isolate small buttons: 18 - Can isolate large buttons: 21 - Good strength: 20 Fine-motor difficulties - Clumsy pen grip: 10 (fine-motor control difficulty) - Tight pen grip: 3 - Motor planning: 19 - Poor muscle directing capacity: 18 - FM tasks difficult & time consuming: 18 - May tire quickly at FM tasks: 15 - Motor tension: 4 - Slight hand tremor: 1 - Limited wrist movement: 6 - Wrist dip (muscle hypertension): 6 - Weak grip: 1 - Finger dexterity difficulties: 10 - Short fingers: 2 - Tense fingers: 2 (1 clawed) - CP in right hand Draw a line - Straight line: 12 - Slightly wobbly line: 5 - Wobbly line: 2 - Very wobbly line: 1 - Scribble: 1 Further physical details - Delayed motor milestones: 13 - Poor muscle tone: 2 - Poor sense of body outline: 2 - Sensitive to touch: 2 - Tremor: 3 - Cerebral Palsy in legs and right arm: 1 - Bend in spine: 1 - Soft collar to support neck: 1

	Input Device Operation Suitable position - Sitting: 17 - Standing: 11 Access movement - Hand: 21 - Arm: 20 - Fingers: 15 - Legs: 14 - Trunk: 9 - Head: 2 - Eyes: 1 - Feet: 11 possible
b) Cognitive abilities	**BPVS-II (British Picture Vocabulary Test)** - Test of receptive English vocabulary - Correlates highly with verbal intelligence Extremely low score range: 19 Bordering extremely low/moderately low score: 2 - F age 8:04 - M age 16:11 **MAT-SF (Matrices Analogies Test – short form)** - Test of non-verbal reasoning Extremely low score range: 18 Low score range: 2 - F 8:06 - M 8:06 Average score range: 1 - M 7:05
C) Perceptual abilities	Visual perception - Immature sensory abilities: 6 - Wears glasses: 7 - Has a squint: 6 - Horizontal/vertical eye jerkiness: 4 - Vertical eye crossing: 3 - Normal Vision: 21 Auditory perception - Auditory processing difficulties: 14 - History of ear infection/hearing difficulties: 6 - Mild hearing loss: 1 - Hearing impaired (left ear): 1 - Hypersensitive to loud noise: 2 - Normal hearing: 17 - Listens well: 12 - Ear for rhyming words: 1 - Recognises happy & sad sounds: 1 Visual-motor perception difficulties - Spatial awareness: 17 - Directionality: 15 - Inattention: 8 - Visual-spatial perception: 12 - Ordering and sequencing: 11 - Sense of rhythm: 12 - Rate and timing: 3

	- Left/right discrimination: 11 - Mixed laterality: 13 - Bilateral tasks: 12 - Asymmetry: 4 - Veers left: 3, veers right: 2
d) Communication	- Use Makaton signing: 21 - Quite good verbal communication: 3 - Short sentences: 9 - One or two word speech: 6 - Signs, gestures and some vocalising: 3 - Stutter: 2 - Quiet speech: 5 - Repetitive speech: 1 - Signing difficult due to fine-motor dexterity: 3 - Computerised voice aid: 2
e) Behaviour	- Sociable: 8 - Helpful: 5 - Sense of humour: 9 - Persistent: 7 - Enthusiastic: 9 - Slightly distractible: 5 - Distractible: 5 - Impulsive: 5 - Fidgets: 2 - Some anxiety: 13 - Lacks self-confidence: 3 - Needs encouragement/prompting: 6 - Hesitant: 3 - Can be stubborn: 2 - Rushes to complete tasks: 3
f) Motivations	Stories 5, books 4, reading 2 Music 7, playing instruments 1, singing 3, dancing 4 Drama 3, theatre 1, art 5, writing 3 Sport 10, i.e. football and swimming Fashion 1, shopping 1, socialising 1 Motor bikes 1 Job interests: nursery nurse, hairdresser, singer Skilled at - Dancing: 3 - Sport: 4 - Drama: 1 - Art: 1 - Music: 2 - Creativity: 2

Context Report - Section 2. Task analysis

School Characteristics	Details
Purpose	To learn and develop emotionally and socially
Hours of work	9 – 3:15 (school hours)
Hours using product	~ 30 minutes; depends on attentions span; could be used in IT lessons
Work flexibility	16+ depart. Can choose to do IT or not; can choose to use in leisure time; if system shown to be very beneficial, then all students should have a go
Task Characteristics	**Details**
Tasks for evaluation	VE navigation and interaction; perhaps not 2D software navigation and interaction
Task goal	VE navigation: explore the VE to learn and enjoy the experience VE interaction: to interact with VE objects and items to learn and enjoy the experience 2D software navigation: view software to learn and enjoy the experience; to be able to interact with the software 2D software interaction: to interact with the software to learn and enjoy the experience
Choice	Could choose not to use for leisure; if shown to be beneficial it would be advantageous for the students to use it
Task output	Good control of VE (navigation and interaction); virtually independent control of VE; effective, efficient and satisfactory use of VEs and 2D software (if being evaluated)
Side effects	Look at relevant health and safety issues; ensure that user not prevented from learning to use a device that they should, i.e. mouse
Task frequency	1 or 2 times per school week
Task duration	Depends on individuals attention span; ~30 minutes; depends on VE
Task flexibility	Tasks carried out according to VE being used; not predefined exactly which tasks are carried out first
Physical demands	Should not be very physically demanding, unless designed to be
Mental demands	Clear understandable interface and function of input device
How demanding in comparison with other tasks?	Navigation is more mentally demanding than interaction, as different functions to choose from
Task dependencies	Computer processor and monitor; software; workstation; teacher/carer assistance
Linked tasks	If VE is reward for 2D work – user first required to complete 2D work; if VE is a virtual experience of 2D work – may first have to do some 2D work
Criticality of task output	The tasks could help to enhance the life of some people with moderate/severe learning difficulties

Context Report - Section 3. Environment analysis

Organisational Environment

Structure	Details
Group Working	Students would work alone or in small groups (2 to 3); collaborative VEs
Assistance	Teacher, carer or technical staff assistance may be required
Interruptions	Other students may distract the user (~4 times per half hour)
Management structure	Teachers are responsible for the work the students are doing with the VEs
Communications structure	The skills learnt can be transferred to real life situations, increase independence
Attitudes & Culture	**Details**
IT Policy	IT is a subject taught in most schools
Worker/user Control	**Details**
Performance monitoring	User progress could be monitored by the computer or software package; the teacher could assess whether the student is learning (observation, discussion)
Performance feedback	The software could give feedback on user progress to encourage or prompt the user/ teacher discussion with student about their performance
Pacing	Students able to work at their own pace; teacher or software prompting user if working too slowly

Technical Environment

Hardware	Details
Required to run the product	Computer processor; computer monitor; network (collaborative VEs); internet connection; workstation
Encountered when using the product	Printer to print work done
Software	**Details**
Required to run the product	Windows; VE platform
Encountered when using the product	WWW browser
Reference Materials	**Details**
To assist with technical environment	Visual manual for system set-up

Physical Environment

Environmental Conditions	Details
Atmospheric conditions	Not humid; similar to SO, conform to standards for school working conditions
Auditory conditions	In classroom: activity of other students and teachers, desks and chairs moving, other software sound, teaching tapes and music, police car or fire engine outside In IT or quiet room: other students activity, teacher communication, other software sound, students outside room Note: in some special schools, primary students can be distractible and classroom can be noisy
Thermal environment	Not too hot, air conditioning?
Visual environment	Classrooms: plenty of natural light Cyber Café: small high windows, lights are not too bright, can see software and hardware clearly
Environmental instability	No difficulties
Workplace Design	Details
Space & furniture	Available: desks (not adjustable), school chairs, adequate space (not cramped)
User posture	Sitting to use the product
Location of product	On the table or desk (workstation); centred or at the side, which is most accessible for the student
Location of workplace	In classroom: teacher assistance available, distractible environment In Cyber Café: teacher assistance (may not be own teacher), quite distractible In IT/quite room: would require teacher/carer to leave class to be with student, less distractible environment
Health & Safety	Details
Health hazards	Ensure input device will not induce physical difficulties; ensure clear access to workstation to avoid tripping; conform to health and safety standards

Product Environment (USERfit)

Function	Who will do this?	How will this be done?
Training needs	Teachers and technical staff	VE to learn how to use input device(s); instructions on how to use input device(s); instructions on how to set-up system
Documentation	Design engineer	Instructions to set-up and maintain the system
Installation	Technical staff	Following step-by-step instructions
Maintenance	Teachers/technical staff/retailer or manufacturer	Follow instructions on maintenance; telephone or send product back to retailer or manufacturer
Support	Teachers/technical staff/retailer or manufacturer	Teacher or technical staff available to assist; telephone retailer or manufacturer
Decommission	Teachers/technical staff/retailer or manufacturer	Put into rubbish bin; send to retailer or manufacturer to reuse parts

User D – characteristics and video analysis

Note: the video was taken for the input device evaluation (see Chapter 3)

Table 1. User characteristics

Fine motor ability Poor pen grip Poor muscle directing capacity Poor strength Gross motor ability Difficulties in general Can use touch screen Avoids weight bearing in arms Perceptual difficulties Spatial awareness Auditory processing Cognitive ability Moderate to severe learning difficulties	Behaviour Determined to achieve Happy/friendly Sense of humour Communication Mostly Makaton signing Started using computerised voice aid Further points Dandy Walker Syndrome & Hydrocephalus Require adaptable workstation Musically gifted

Range of Movement test

- Upper extremity – requires trunk support; shoulder, elbow & wrist movement fine
- Strength – weak grasp
- Finger dexterity – weak grasp; can isolate finger press (but weak press)

Table 2. Video analysis observations

Joystick (Axys) • Using joystick on lap • Sufficient strength to control himself • Left hand holding joystick on lap, right hand used to move stick • Right hand control of stick a bit unsteady, require increased resistance to movement Mouse • Reaching far (outside reach envelope) to use mouse, having to move forward in pushchair • Due to reaching forward, not covering whole of mouse with hand, just the bottom 3rd of the mouse • Not able to hold mouse and press button at same time • Sufficient strength to push mouse button by himself • Can move mouse by gripping with three fingers on one side, thumb on other side and one finger on top • Can grip mouse, but hand circumference small, so width of mouse looks a bit large for him General • Desk too high for him • Having to look up at screen, as desk is too high • Workstation must accommodate his special chair • Can clench fingers on left hand • Can clench fingers on right hand • Right hand bent down slightly at wrist • Answers yes, by shaking hand up and down at wrist • Using right hand to move stick and operate mouse

User E – characteristics and video analysis

Note: the video was taken for the input device evaluation (see Chapter 3)

Table 1. User characteristics

Fine motor ability Clumsy pen grip Poor muscle directing capacity Good grasp strength Good finger dexterity Gross motor ability Scoliosis (bend in spine) Coordination difficulties Wide steps; unusual feet position Perceptual difficulties Immature sensory-motor Motor planning Bilateral integration Poor balance (auditory processing) Left-right discrimination	Cognitive ability Severe learning difficulties Sequencing & ordering difficulties Behaviour Easily distractible Hyperactive; fidgets Further points Microcephalic (small head) Organising – too many stimuli may overwhelm him Communication Speech difficulties Sounds and gestures to support communication

Range of Movement test

- Upper extremity – fine
- Finger dexterity – good
- Midline crossing difficulty
- Pegs – quite poor placement

Table 2. Video analysis observations

Joystick (Axys) • Before started, randomly pressing button on top of joystick • Desk too high for him • Bend in spine, doesn't cause posture difficulty when sat down, not bent over too much • Sitting forward on end of chair, not look comfortable Mouse • Put right hand over mouse correctly, fingers covering buttons too much, would not be easy for him to press the correct mouse button General • Can make a fist with right hand • Movement in arms/wrists looks fine • Always using right hand, for joystick and mouse • Looking straight at screen

User H – characteristics and video analysis

Note: the video was taken for the input device evaluation (see Chapter 3)

Table 1. User characteristics

Fine motor ability Clumsy pen grip Poor muscle directing capacity May tire quickly Gross motor ability Coordination difficulties Balance difficulties Clumsiness Perceptual difficulties Motor planning Spatial awareness Directions Horizontal eye jerkiness Vertical crossing of eyes Wears glasses	Cognitive ability Severe learning difficulties Ordering and sequencing difficulties Behaviour Depression Some anxiety Under confident Communication Speech difficulties, uses Makaton signing Further points Requires encouragement

Range of Movement test

- Upper extremity – fine; including reach
- Strength – fine
- Finger dexterity – good

Table 2. Video analysis observations

Joystick (Axys) • Uses right hand • Able to grip • Rests arm on work surface, although there is not quite enough space Mouse • Uses right hand • Grip is fine • Use of button is fine General • Desk height is suitable for her • Looking at the computer screen

Appendix G

- User Analysis Questionnaire (UAQ)
- UAQ feedback

Questionnaire on User Analysis Data

Please fill in the right column of each table, with details of how the user data, in the left column, might affect the design of a computer input device for people with learning difficulties. Any design requirements, which relate to the user data, would be greatly appreciated. **Thank you.**

Epilepsy	May present with a tremor. May " with absences ∴ need time delay or sustained control to allow return to present position.
Serious heart condition	Limit 'stress' induced situations.
Hypotonic	Light weight control device. May present with variable grip strength and Range of Movement (R.O.M.) Difficulty reaching out to extremes/above head.

(poor proximal stability - shoulders/hips).
May require support (postural) ie when standing/sitting.

Gross-motor abilities

Co-ordination difficulties	May limited navigation + direction of device.
Motor-planning difficulties	Requires clear, simple instructions to move device May have difficulty if ideation required. Stable devise ie joystick - to move device in specific directions. Mouse would be difficull
Body symmetry difficulties	Bilateral integration difficulties - crossing midl Difficulty co-ordinating (L) + (R). Unilateral or bilateral control
Balance difficulties	position of self in relation to equipment. level of postural support required in sitting or sta difficulty reaching out of base of support.
Poor muscle directing capacity ?	
Motor tension ?muscle tone.	High Tone - Limited, rigid R.O.M. } Observable. Low Tone - slow heavy movement }

Will impact on static + dynamic movements.

Fine-motor abilities

Tremor	Need to stabilise/fix elbow/wrist on work surface ie elbow on table top. use of mouse or keyboard maybe difficult due to reduced accuracy + poor co-ordin Joystick better
Wrist dip	Limited wrist extension ∴ Limited control & movem consider position of device in relation to wrist & hand.
Weak grip	Light weight. Variable grasp size/shape. Easy to guide.
Tense or clawed fingers	Narrow handle. ?strap to secure device.
Cerebral palsy in hand	All of the above.
Delayed motor milestones	Developmentally appropriate ie activity level & co ?achieved full range of grasp; in hand manipulat bilateral co-ordination; and/or tool use & control
Poor muscle tone	may present with weak grasp; poor pincer grasp limited R.O.M and/or reduced in-hand manipulation.
Poor sense of body outline ?	
Sensitive to touch	?tactile defensive – if so, would not be advised to enforce handling of objects. be aware of materials used.
Bend in spine	Postural support may be required in standing or sitting upper limb R.O.M may be limited.

Visual & auditory perception

Immature sensory abilities	Needs to be 'developmentally' appropriate. ? limited interpretation of task.
Has a squint	may affect visual attention & visual focus may head turn to compensate. Difficulty isolating head & eye movement
Horizontal/vertical eye jerkiness "NYSTAGMUS"	As above. movement & balance may be affected

Vertical eye crossing	
Auditory processing difficulties	Visual vs auditory cues provided. ? how instructions given. ? how feedback is received.
History of ear infection	As above.
Hearing difficulties	As above.

Visual-motor perception difficulties

poor coordination when reaching ie over or under [cut off] for car[cut off] direc[cut off]

Spatial awareness	Orientation, Navigation, Motor Planning } can be impaired.
Directionality	As above.
Inattention	following of instructions, visual focus, continuity } could be limited.
Visual-spatial perception	Depth perception – as spatial awareness
Ordering & sequencing	Difficulty following instructions/ patterns/ pathways
Sense of rhythm	Poor flow of movement / activity.
Rate and timing	Decreased accuracy
Left/right discrimination	Navigation, co-ordination, interpretation of direction } may be impaired.
Mixed laterality	Bilateral vs unilateral control.

* consider each child's ability to interpret / recognise 3D information.

Asymmetry	consider postural needs. direction + navigation.
Veers left or right (motor tasks)	May impact on control of device / direction / accuracy.
Poor co-contraction	

Behaviour

Impulsive	motivation & attention to task may be affected.
Distractible	visual attention + focus } following of instructions } may be affected. minimise distractions.
Lacks self-confidence	developmentally appropriate skill level. sense of achievement - realistic goals. positive re-inforcement.
Hesitant	positive encouragement. simple, clear instructions. achieveable tasks (realistic expectations)
Can be stubborn	
Rushes to complete tasks	Requires staged tasks.

User analysis questionnaire (feedback)

Note: the answers from each questionnaire reply are noted in a different colour

Condition	Symptoms	Design requirements
Epilepsy	Tremor; lose consciousness	Time delay/sustained control (with absences, to allow return to present position); avoid flashing lights and certain patterns (may induce fit); safe to fall on (smooth edges); robust device (knocks)
Serious heart condition		Limit 'stress' induced situations; good posture (B.P. related); robust (knocks)
Hypotonic	Variable grip strength and range of movement (ROM); difficulty reaching out to extremes (above head); poor stability in shoulders/hips	Light weight control device; allow for variable grip strength and range of movement; minimum reach possible; may require postural support; arm/hand support; adjustable workstation

Gross-motor factors	Symptoms	Design requirements
Coordination difficulties	Child may be better at gross motor movement	Minimum control directions possible; variable sensitivity; easy to interface; direction indicators/guides; audible guide
Motor-planning difficulties	Difficult to plan motion sequence and to link motion to VE reaction	Clear, simple instructions (visual/audible); stable device; directions are specific; concrete cues; movement assistance

Body symmetry difficulties	Bilateral integration difficulties, crossing midline	Unilateral or bilateral control; symmetrical posture?; directional cues; balancing of device (calibration with computer)
Balance difficulties	Difficulty with position of self in relation to equipment; difficulty reaching out of base of support	Provide postural support; minimum reach possible; sitting to use; stable device
Poor muscle directing capacity		Variable ROM; buttons, easy to actuate; utilise user's best movements
Muscle tone	High tone – limited, rigid ROM; low tone – slow heavy movement; impact on static and dynamic movements; may lock in grip	Muscle support; soft material; not have to grip

Fine-motor factors	Symptoms	Design requirements
Tremor		Stabilise/fix elbow/wrist on work surface; damp out tremor (calibration); muscle support
Wrist dip	Limited wrist extension – limited control and movement	Careful positioning of device in relation to wrist/hand; ergonomic design; muscle support
Weak grip		Light weight; variable grasp size/shape; easy to guide; variable sensitivity; not have to grip
Tense or clawed fingers		Narrow handle; strap to secure device; accessible buttons
Cerebral palsy in hand		All of the above; calibration; one device for all tasks
Delayed motor milestones	May not have achieved full range of grasp; motor coordination, muscle tone and motor-planning may be effected; inhibited primitive reflexes	Developmentally appropriate activity level and control

Poor muscle tone	Weak grasp, poor pincer grasp; limited ROM, reduced in-hand manipulation; no fix at shoulders and hips etc.	Easy to grip; not require pincer grasp; variable ROM; minimal in-hand manipulation
Poor sense of body outline	Difficulty with midline crossing	Direction indicators; avoid cross-lateral movements at start; comfortable material
Sensitive to touch	Tactile defensive? – not enforce handling of objects; may touch hard, but not soft things	Appropriate materials/texture; device/support cover
Bend in spine	Upper limb ROM may be limited	Postural support; minimal ROM required; adjustable workstation

Visual & auditory perception	Symptoms	Design requirements
Immature sensory abilities	May have processing difficulties	Developmentally appropriate; limited interpretation of task; device positioned appropriately in relation to screen; adjustable VE/movement/cursor speed
Has a squint	May affect visual attention and focus, may head turn to compensate; difficult to isolate head and eye movements	Device/screen positioned carefully
Horizontal/vertical eye jerkiness (Nystagmus)	As above; movement and balance may be affected	As two above
Vertical eye crossing		As above; focusing adjustment
Auditory processing difficulties	Appreciation of sound associated with computer vs. background sound	Visual vs. auditory cues provided; visual instructions and feedback; adjustable sound (including tone/volume)
History of ear infection	Balance effected	

Visual-motor perception difficulties	Symptoms	Design requirements
Spatial awareness	Poor coordination when reaching (i.e. over or under reach); orientation, navigation and motor-planning can be impaired	Directional cues; feedback (gone right way)
Directionality	As above	As above; program – positive reinforcement
Inattention	When following instructions, visual focus and continuity could be limited	Motivational; feel (texture); feedback (visual/auditory/haptic); close link from device to software
Visual-spatial perception	Depth perception difficulties; light sensitivity; visual discrimination difficulties	Limited visual stimuli
Ordering and sequencing	Difficulty following instructions, patterns and pathways	Simple instructions; limited operations
Sense of rhythm	Poor flow of movement/activity; difficult to press something continuously	
Rate and timing	Decreased accuracy	Adjustable speed of VE/movement
Left/right discrimination	Navigation, coordination and interpretation of direction may be impaired	Visual cues
Mixed laterality	Bilateral vs. unilateral control; visual tracking Can be poor	Direction cues; one hand operation; adjustable speed VE/movement
Asymmetry	Consider postural needs, direction and navigation; may favour one side of program over other	Calibration
Veers left or right (motor tasks)	May impact on direction and accuracy	As above
Poor co-contraction		Stable device; robust; can be repositioned

Behaviour	Symptoms	Design requirements
Impulsive	Motivation and attention to task may be affected	Adjustable speed of device/VE; motivating; rewards
Distractible	Visual attention/focus and following instructions may be affected	Minimise distractions; motivational
Lacks self-confidence		Developmentally appropriate skill level; gives a sense of achievement; realistic goals; positive reinforcement; easy to learn; feedback
Hesitant		Give positive encouragement; simple, clear instructions; realistic expectations; as above
Can be stubborn		Motivational; age appropriate; challenging/topical
Rushes to complete tasks	Requires staged tasks	Intermittent rewards

Appendix H

- Requirement Specification
- Design Specification

Requirement Specification

1. User Analysis

User Group	Design Requirements
Size of group: 21 (5 primary, 8 senior and 8 from 16+)	
Age range: 7:05 to 19:00	Age appropriate appearance (7 – 19) Appearance fits environment (classroom) Adaptable appearance to suit user group Ergonomic design for age 7 – 19
Gender: 9 female and 12 male	Appropriate appearance for males and females
Syndromes, i.e. Downs Syndrome: 5 CP in both legs and right arm: 1	Appeal to non-special needs market Can be used in a sitting position
Epileptic: 3	Robust construction, shatterproof
Serious heart condition: 1	Conform to health and safety standards
Hypotonic: 1 (may tire easily)	Provides muscle support (arm, hand)

Skills & Knowledge	Design Requirements
Can use switches: 21	Buttons/switch – appropriate size and position, easy to operate
Can use a touch-screen: 19 (2 with motor control difficulties)	Touch-screen can be used for interaction (adjustable positioning)
Good joystick control: 9	Navigation – could mimic joystick input to PC
Joystick difficulty: 9 cognition, 3 motor	Adaptable to user's cognitive and physical ability
Good mouse control: 10	Interaction – mimic mouse input to PC
Mouse difficulty: 8 cognition, 3 motor	Adaptable to user's cognitive and physical ability Conforms to BS for computer interface devices
Copy types (keyboard), needs capitals: 5	Avoid typing for input method
Used VEs before: 6	Introduction VE
Can switch on computer and load a program: 4	Instructions on how to set-up VE system for use
Learning cause and effect	Range of difficulty settings Step-by-step training to use device(s)is provided
Enjoy using the computer: most students	Enjoyable to use
Skilled at: Dancing: 3, Sport: 4, Drama: 1, Art: 1, Music: 2, Creativity: 2	

Attainments	Design Requirements
Remembers sequences of activities: 9	Minimum user input for task completion
Reads his/her name and classmates: 10	Instructions – visual and demonstrational
Completes reading workbooks: 4	VEs with simple written instructions can be followed by the more able students
Good understanding of addition and subtraction: 5	Addition and subtraction can be included in VEs for more able students
Does simple probability work: 1	VE to teach probability and other maths concepts
Understand function of money: 5	Money concepts can be taught within VEs, starting very basic and progressing
Understands time (1/2, ¼ pas): 5	VE to teach time concepts, starting with very basic and progressing
Good cognition of shapes: 7	Use simple shapes for visual cues, i.e. square and circle
Copy write: 7	VE requires no writing input, unless the VE is for developing writing skills

Physical Abilities: Gross-Motor	Design Requirements
Independently mobile: 20	Ensure clear access to workstation
Good reach ability: 15	Possible to adjust position of device
Unsteady gate: 3	Can be used in a sitting posture
Tires quickly when walking: 3	Does not require walking
Uses a walker: 1	Ensure clear access to workstation with walker
Uses Lecky Chair & Major Buggy: 1	Workstation accessible with special chairs / walker
Unsteady arm movement: 2	Provides muscle support (arm, hand) Will not detect unintentional movements, i.e. tremor
Tense arm: 1	Detects range of motion Relaxing and comfortable to hold
Can't fully stretch right arm: 1	Operated with left or right hand/arm
Requires trunk strengthening: 2	Ergonomic design of workstation
Weight bearing in arms difficult: 2	Avoids weight bearing in arms
Co-ordination difficulties: 14	Adaptable to user's physical ability Slots/guides to assist user action Operated with left or right hand/arm
Motor planning difficulties: 18	Provides visual cues, auditory and haptic cues to function Step-by-step training to use is provided User controls pace of interaction
Body symmetry difficulties: 14	Operated with left or right hand/arm
Balance difficulties: 16	Can be used in a sitting posture

Physical Abilities: Fine-Motor	Design Requirements
Good pen grip: 11	Can be gripped
Can isolate small buttons: 18	
Can isolate large buttons: 21	Button/switch – appropriate size and position, easy to operate
Good strength: 20	Adjustable resistance to movement Withstands quite forceful use
Clumsy pen grip: 10 (fine-motor control difficulty)	Suitable hand/arm interface
Tight pen grip: 3	Relaxing and comfortable to hold
Motor planning: 19	Provides visual cues, auditory and haptic cues to function Step-by-step training to use is provided
Poor muscle directing capacity: 18	User action can be assisted Detects range of motion
FM tasks difficult & time consuming: 18	Relaxing and comfortable to hold Adaptable to user's physical ability
May tire quickly at FM tasks: 15	Can be operated in different ways Minimum user input for task completion
Motor tension: 4	Provides muscle support (arm, hand) Relaxing and comfortable to hold
Slight hand tremor: 3	Will not detect unintentional movements, i.e. tremor
Limited wrist movement: 6	Detects range of motion User action can be assisted Can isolate movement at elbow or shoulder to assist user control
Wrist dip (muscle hypertension): 6	Provides muscle support (arm, hand) Operated with left or right hand/arm
Weak grip: 1	Suitable hand/arm interface Allows for range of user strengths
Finger dexterity difficulties: 10	Avoid complex finger movements Buttons – easy to operate
Short fingers: 2	Buttons – easy to operate
Tense fingers: 2 (1 clawed)	Suitable hand/arm interface Relaxing and comfortable to use
CP in right hand	Operated with left or right hand/arm

Further Physical Details	Design Requirements
Delayed motor milestones: 13	
Poor muscle tone: 2	Allows range of user strengths
Poor sense of body outline: 2	Provides visual cues to interface
Sensitive to touch: 2	Comfortable to hold
Bend in spine: 1	Ergonomic design of workstation
Soft collar to support neck: 1	Possible to adjust position of device Adjustable workstation

Input Device Operation	Design Requirements
Sitting to operate: 17	Can be used in a sitting position
Standing to operate: 11	Could be used standing (by some users)
Using the hand: 21	Can be operated with left/right hand
Using the arm: 20	Can be operated with left/right arm
Using the fingers: 15	Avoid complex finger movements
Using the Legs: 14	Legs – not the primary access method
Using the trunk: 9	Trunk – not the primary access method
Using the head: 2	Head – not the primary access method
Using the eyes: 1	Eyes – not the primary access method
Using the feet: 11	Feet – not the primary access method

Cognitive Abilities	Design Requirements
BPVS-II: Extremely low score range: 19	Instructions – specific, simple, step-by-step, visual, demonstrational User actions similar to VE actions Minimum user input for task completion Can be used independently
BPVS-II: Bordering extremely low/moderately low score: 2	Range of difficulty settings Is consistent (no guessing required) Automatic return to zero/centre position
MAT-SF: Extremely low score range: 18	Only the necessary functions are available Easy to learn how to operate the device Step-by-step training to use is provided
MAT-SF: Low score range: 2	Provides a variety of support levels Teacher assistance available
MAT-SF: Average score range: 1	Adaptable to user's cognitive ability

Visual Perception	Design Requirements
Immature sensory abilities: 6	Possible to adjust position of device
Wears glasses: 7	
Has a squint: 6	
Horizontal/vertical eye jerkiness: 4	Touch-screen can be used for interaction (adjustable positioning)
Vertical eye crossing: 3	
Not focusing on object	Is transparent
Normal Vision: 21	Appropriate for colour blind

Auditory Perception	Design Requirements
Auditory processing difficulties: 14	Auditory cues are simple and clear
History of ear infection/hearing difficulties: 6	Visual and haptic cues to interface and function
Mild hearing loss: 1	Visual and haptic cues to interface and function
Hearing impaired (left ear): 1	Auditory cues, not the only method of assistance available
Hypersensitive to loud noise: 2	Auditory cues or feedback can be turned down or off
Normal hearing: 17	Auditory cues and feedback can be used
Recognises happy & sad sounds: 1	Use interesting auditory cues and feedback

Visual-Motor Perception Difficulties	Design Requirements
Spatial awareness: 17	Provides visual cues to interface and function Any visual, auditory and haptic cues are simple and clear User actions similar to VE actions
Directionality: 15	Obvious orientation of device Slots/guides to assist user action
Inattention: 8	Provide additional cues to interface and function (auditory and haptic) Provides feedback – visual, auditory and haptic (can be switched off)
Visual-spatial perception: 12	See spatial awareness Cues to interface and function can be removed as user progresses (if possible)
Ordering and sequencing: 11	Minimum user input for task completion
Sense of rhythm: 12	
Rate and timing: 3	User controls pace of interaction Accepts range of user action speeds
Left/right discrimination: 11	Provides visual, auditory and haptic cues to function
Mixed laterality: 13	Provides visual, auditory and haptic cues to function
Bilateral tasks: 12	Operated with left or right hand/arm Can be operated using both sides of body together
Asymmetry: 4	Operated with left or right hand/arm
Veers left: 3, veers right: 2	Has biasing control function
Poor co-contraction	Detects range of motion
Clumsy, inflexible movement	Withstands quite forceful use Allows for range of user strengths

Communication	Design Requirements
Use Makaton signing: 21	Can use Makaton symbols
Quite good verbal communication: 3	Should not require any verbal ability
Signs, gestures and some vocalising: 3	Signs, gestures and noises can be used for input
Quiet speech: 5	If vocalising used, must detect quiet speech
Signing difficult due to fine-motor dexterity: 3	Signing is not the only method of input used
Computerised voice aid: 2	

Behaviour	Design Requirements
Sense of humour: 9	Enjoyable to use
Persistent: 7	VEs allow students to progress
Enthusiastic: 9	Adaptable to user's cognitive and physical ability
Slightly distractible: 5	Is transparent
Distractible: 5	Is transparent No excess functions accessible
Impulsive: 5	Enjoyable to use Easy to learn how to operate
Fidgets: 2	Difficult to deconstruct (pull apart)
Some anxiety: 13	Can be used independently Step-by-step training is provided
Lacks self-confidence: 3	Step-by-step training is provided
Needs encouragement/prompting: 6	Provides a reward (if appropriate) Provides feedback – visual, auditory and haptic
Hesitant: 3	Functional clarity for navigation and interaction tasks
Can be stubborn: 2	Age, gender and developmentally appropriate
Rushes to complete tasks: 3	Enjoyable to use / motivating Easy to learn how to operate

Motivations
This list is indicative of the sorts of VEs which might appeal to the user group Stories 5, books 4, reading 2 / music 7, playing instruments 1, singing 3, dancing 4 Drama 3, theatre 1, art 5, writing 3 / sport 10, i.e. football and swimming Fashion 1, shopping 1, socialising 1 / motor bikes 1 Job interests: nursery nurse, hairdresser, singer

Input Device Evaluation

Navigation factors	Design Requirements
Random movement of device, disorientation – 7	Clear, understandable operation VE for training input device use
Too much left/right rotation, spinning – 5	Adjustable resistance to movement (may help to prevent some disorientation)
Trying to use for interaction – 3	Functional clarity for achieving navigation and interaction tasks
Button misuse – 6	Not easy to press buttons by mistake
Base held still by examiner – 4	Ensure that base of device remains stationary during operation
Physical help with some tasks, alignment guidance – 6	Able to use the device independently Facilitates task completion
Used two hands, tight grip – 5	Ergonomic design of device

Interaction Factors	Design Requirements
Random movement of device – 4	Clear, understandable operation VE for training input device use
Frequent pressing of buttons, pressing wrong button - 3	Not easy to press buttons by mistake Only possible to press buttons which are required
Physical help with some tasks, held still to press button – 5	Able to use the device independently Consider physical abilities of the user group
Not gripping around the sides – 2	Ergonomic design of device

Further assessment measures	Design Requirements
Prompting as to which device to use for a task – 3	Functional clarity for achieving navigation and interaction tasks Only have one input device for navigation and interaction tasks
Encouragement, some distraction / distracted – 3	The device gives feedback The device is motivating to use Develop motivating VEs that are appropriate for age and developmental stage
Attention on devices when using them – 10	Device is transparent
Weak grip, shaky hand/arm – 2	Consider physical abilities of the user group
Desk too high – 3	Adjustable workstation
In Major Buggy – 1	Consider accessibility to the workstation
Fidgets in seat – 2	Workstation helps to engage the user

2. Task Analysis

Navigation within a virtual environment	**Design Requirements**
Locate navigation device	Possible to adjust position of device
Establish contact with navigation device	Provide visual cues to interface
Decide on desired movement in VE	Adequate information – task completion
Use device to cause desired movement in VE	Provides visual, auditory and haptic cues to function Step by step training to use is provided
Stop action with device, to stop movement in VE	Provides closure
Decide next action to perform in VE	Adequate information – task completion

Interaction with objects within a VE	Design Requirements
Locate object/item to interact with or select	Navigation and interaction devices are both accessible and have adequate space for use
Locate interaction device	Possible to adjust position of device
Establish contact with interaction device	Provide visual cues to interface
Use device to move cursor over VE object/item	Ergonomic design of interface for age 7-19 Provides visual, auditory and haptic cues to function Teacher assistance available
Use device to select/interact with VE object/item	Easy to operate buttons Interaction device stationary to operate button/switch
Decide next action to perform in VE	Adequate information – task completion

Task Characteristics	Design Requirements
Side effects: From physical interaction and computer use	Conform to health and safety standards
Task frequency: 1 session per week or fortnight (each student)	Withstands frequent use
Task duration: ~ 30 mins (dependent on student attention span)	Durable
Physical demands: Required to use a device to control 3d navigation and interaction	Adaptable to user's physical ability
Mental demands: To understand 3d navigation and interaction	Only necessary functions are available Functional clarity for navigation and interaction tasks
Task dependencies: Computer software, processor and monitor	Workstation accommodates necessary hardware and allows teacher to view student's work
Linked tasks: VE may relate to class-work	

3. Environment Analysis

Organisational Environment	Design Requirements
Group working: Work alone or in small groups (2 to 3); collaborative VEs	2 to 3 peers able to assist user Designed for one person to use it
Assistance: Teacher/carer may be required	Allows teacher to view student's work Teacher assistance available
Interruptions: Other students may distract user	Workstation helps to remove distractions
Performance monitoring: Computer software could record session/level reached; observation by teacher/carer	VE guidelines
Performance feedback: Score or time taken given; intelligent agent reports 'well done', 'better luck next time'	VE guidelines
Pacing: Able to work at own pace or against a clock	User controls pace of interaction

Technical Environment	Design Requirements
Hardware required to run product: Computer processor and monitor; internet (collaborative VEs)	Workstation accommodates necessary hardware Access to internet (if appropriate)
Software required to run product: Windows and VE platform	Compatible with VE software Compatible with Windows system
Reference materials: Manual for system set-up and maintenance	Instructions – visual, clear and concise

Physical Environment	Design Requirements
Atmospheric conditions: School working environment	Conform to BS for computer environment
Auditory conditions: Noise of teachers, students and equipment	Workstation helps to remove distractions Primary students may require workstation not to be in classroom
Visual environment: Suitable for computer use	Conform to BS for computer environment
Location of workplace: In classroom, IT or quiet room	Workstation helps to focus attention on VE
Space and furniture: School desks and chairs available; adequate space to move around	Ensure clear access to workstation (cables kept free from workstation) Only required hardware on workstation Conform to BS for computer workstation design
User posture: Sitting when using the system	Ergonomic design of workstation (users 7-19)
Location of product: On table or desk, centred or at the side	Possible to adjust position of device
Health and safety: Access to workplace, computer use and physical interaction	Conform to health and safety standards Conform to any BS for computer interface devices

Design Specification

Key for basic, performance and excitement requirements

- Basic – (b)
- Performance (p)
- Excitement – (e)

1. Product Appearance

Design Requirements	Device Attributes
Appearance fits environment (class)	Modern style, attractive colours (b) Compact design (p)
Age appropriate appearance (7 – 19)	Style 1 – toy like, fun; colour can catch imagination (b) Style 2 – modern, racy, attractive colours (b)
Appropriate appearance for males and females	Style – not feminine or masculine (b)
Appropriate for colour blind	See colour deficiency section (p)
Appropriate for epileptic	*Avoid flashing lights / certain patterns (p)*
Appeal to non-special needs market	[Modern style, attractive colours]
Adaptable appearance to suit the VE	Overlays/laminated cards

2. Ergonomic Design

Design Requirements	Device Attributes
Conforms to any BS for computer Interface devices	See BS section (b)
Ergonomic design for age 7 – 19	Ergonomic design of user interface (variable size/weight) (b)
Can be used in a sitting posture Ensures good posture	Accommodates wheelchair users (b) Ensures neutral operation position (sitting) (p) Ergonomic design of computer workstation (sitting) (p) Variable level of postural support (i.e. lap strap, foot block, hip pads, chest harness etc.) (p)
User doesn't have to grip the device Utilise user's best movements	Can be operated without gripping the device (p) *See grasp section; changeable user interface (p)*
Operated with left or right hand/arm	Operated – left or right hand/arm (b)
Can be operated using both sides of body together	Operated – left and right hands/arms together (p)
Avoid complex finger movements	No fine finger operation required (p)
Provides muscle support (arm, hand); less tremor when hand is within 8 inches above or below heart level	Support: ergonomic design of muscle support (arm/hand) (p); stable in use (b) *Pivot point positioned under point at which wrist rests
Encourage postural change	Operation involves postural change (p)
Can isolate movement at elbow or shoulder to assist user control	Can fix shoulder or elbow to assist user control (p)
Avoids weight bearing in arms	[Ergonomic design of muscle support]
Relaxing and comfortable to hold	Comfortable form for interface (p) Comfortable material for interface (p)
Appropriate texture	Contact surface texture; not too smooth (slippery); not too rough (abrasive) (p)
Accessible	Can be repositioned, without tools (b) *Appropriate position in relation to hand/wrist and screen
Will not cause injury with use, i.e. RSI (WRULD), pressure points	Conforms to health and safety standards (b) Avoid static muscle loading (p) *No sharp edges or raised parts on user interface (b)* [Ensures neutral operation position]

Easy to operate buttons	Buttons – appropriate size, shape and position, actuation resistance (p) Buttons – not easily actuated accidentally (p) See button design; detachable buttons (p)
Interaction device stationary to operate button/switch	Can be fixed to the workstation / weighted base (p)
Designed for one person to use it	Designed for one person to use (b)
Transportable	Light/comfortable to carry (adult, older student) (b) No loose component parts (b)
Avoid too much head movement	Working area – 100-120 degrees from stationary head position (visual field) (p)

3. Interface and Functional Assistance

Design Requirements	Device Attributes
Provides visual cues to interface (only simple shapes, i.e. circle and square) Concrete cues	Form indicates interface (p) Colour & symbol cues to interface (p) **Simple shapes; possibly Makaton – consistent / conventional; any text – sans-serif; colour not only cue* Light cues to interface; avoid flashing/flickering lights & light patterns (p) *Light sensitivity
Distinctive component parts	Essential details/components highlighted (p) Not cluttered (minimal detail) (p)
Provides visual cues to function	Form indicates navigation control (p) Form indicates how navigation control is achieved (p) Button's form invites user to actuate it (p) Colour and symbol cues to function (p)
Obvious orientation of device	Form indicates device orientation (p)
Provides additional cues to interface (auditory and haptic)	*Textured surface cue to interface (aware of tactile sensitivity) (p)*
Provides additional cues to function (auditory and haptic)	Makes noise with user action (adjustable sound, including tone/volume (p) *Primarily attention / reinforcement); note: hypersensitivity to sound Haptic sensation with user action (p)
Any cues to interface and function can be removed as user progresses	Visual, auditory and haptic support is adjustable (p)
Any visual, auditory and haptic cues are simple and clear	Visual, auditory and haptic cues are simple and clear (p)
Provides direct task-related feedback (i.e. gone right way) - visual, auditory and haptic (can be switched off)	Relevant feedback – visual, auditory, haptic (e) *Feel virtual barriers (i.e. can't move device, excitement)
Related controls grouped	Controls grouped - functional, sequential or frequency grouping (p)

4. Cognitive Factors

Design Requirements	Device Attributes
User actions similar to VE actions	Movement in VE same as user action (p)
Adaptable to user's cognitive ability	Modifiable operation difficulty (starting basic) (p) Modifiable degrees of freedom (p)
Only necessary functions are available	No excess functions accessible (p)
Minimum user input for task completion	One user action = one VE function (p) Avoid human pre and post processing (p)
Directions are specific	Movements are specific (p)
Functional clarity for navigation and interaction tasks; limited interpretation of task	[Form depicts function]
Only have one input device for all tasks	Navigation and interaction functions in one device (p)

Ensure navigation and interaction functions are not conflicting	Switch to select navigation or interaction mode (p)
If separate devices for navigation and interaction, ensure both accessible and adequate space to use	[Can be repositioned] Workstation provides adequate space for device(s) (b)
Natural – self explanatory	Concrete visual, auditory and haptic cues (p)
Can be used independently	*VE/video to learn how to use input device(s) (e)* Manual to learn how to use input device(s) (p)
Easy to learn about the device	Demo of device(s) to user (p)
Easy to learn how to operate the device	[VE to learn how to use input device(s)] [Manual to learn how to use input device(s)]
Is consistent (no guessing required)	Function consistent for individuals (b)
Does not cause stress when using	[Modifiable operation difficulty]
Is transparent	Is not distracting (b) [Movement in VE same as user action] [No excess functions accessible]
Provides closure	Returns to centre position (b)
Provides automatic control of non-essential details	*Intelligent assistance control (e)*
Enjoyable to use / motivating	Accepts enthusiastic operation, robust (b) [Movement in VE same as user action] [Visual, auditory and haptic feedback]
Can develop skill	Function increases user skill (p)
Understandable design model; some users have slower rate of concept development	User model maps to design model (can use analogy) (p)

*5. **Physical Factors***

Design Requirements	Device Attributes
Adaptable to user's physical ability	*Avoid vigorous operation movements (b)* *Range of interface options (p)* Customisable (e.g. colour attachments so devices for particular users readily identifiable) (e)
Allows range of use strengths	Adjustable inertia: power between 0.3 and 0.6 N (p) *Resistance can help to reduce tremor
Allows variable grip strength	Do not have to grip (hand/wrist strap) (p)
Detects a range of motion	Variable range of movement (p)
User action can be assisted, i.e. fix device to hold movement (endurance)	*Provides assistance to user actions; lockable in active positions; slots/guides to assist user actions (e)* Provides necessary assistance (p)
Easy to guide/manipulate	*Smooth operation/action (b)*
Will not detect unintentional movements, i.e. tremor	*Calibration to damp out unintentional movement (tremor, muscle jerks, twitches) (e)*
Requires minimum reach	Positioned for minimum reach (b)
Requires minimal in-hand manipulation	Minimal in-hand manipulation (p)
Avoid cross-lateral movement (initially)	Avoids cross-lateral movement (initially) (p)
Withstands quite forceful use	Robust construction (b)
Stable	*[Can be fixed to work surface or has weighted base]*
Has biasing control function Can be balanced for user	Calibrate balance (p)
Accepts range of user action speeds	Detects fast and slow user actions (p)
User controls pace of interaction	No time limit for user action (p)

6. Usability Factors

Design Requirements	Device Attributes
Operation is obvious/clear/predictable	[Form indicates function] Familiar function (analogy) (e)
Operation is consistent	*Functions and feedback are consistent (p)*
Provides effective feedback	Perceptible and understandable feedback (p)
Does not interfere with own use	Non-interference (i.e. cabling) (b)

7. Construction

Design Requirements	Device Attributes
Robust construction, shatterproof	Strong and flexible casing (p) Parts fit together precisely, accurate part mouldings (b)
Safe to fall on	*No sharp edges or components (b)*
Able to wipe clean	Wipe-proof joints, sealed (b)
Difficult to deconstruct (pull apart)	[Parts fit together precisely] *[No loose component parts]*
Mechanically sound	Robust mechanical design, minimal parts (p)
Non-interference with hearing aid	Electromagnetic characteristics not interfere with hearing aid (p)
Withstands frequent use, durable	[Robust construction] Durable materials (b)
Reliable	[Robust mechanical design, minimal parts] Reliable electronic design, minimal parts (b)
Safely dispose of in domestic waste	Non hazardous materials (b)
Prototypes suitable for evaluation	Prototypes carefully manufactured (b)
Affordable for special needs schools	Use cost effective materials (b) Use low cost manufacture (p)
Can be used on desk in front of computer	[Compact design (will fit on desk in front of computer or wheelchair tray)]

8. Control Functions

Design Requirements	Device Attributes
Control VE navigation	Forward/back movement; left/right turn (b) Left/right movement; look up/down (p)
Ability to navigate through restricted space	Fine movement function (p)
Ability to position cursor/object	Up/down/left/right movement (to position cursor/object) (b)
Control VE interaction	Ability to cause interaction with VE object (activate, pick-up, place, object-object interplay) (b)
Ability to interact with small VE objects	Fine movement function (to position cursor) (p)
Ability to control 2D software functions	Ability to control 2D navigation/interaction (e) *I.e. position cursor; select; drag and drop (compatible with stick-keys; hardware/software lock)
Ability to change function of controls	Device controls are configurable (p)
Further functions can be added	Add-on configurable control pad (e)
Gain appropriate to user/task	Adjustable gain (perhaps in software) (p)

9. Computer Input

Design Requirements	Device Attributes
Compatible with VE software	Compatible with VE software (b) Navigation – could mimic joystick input to PC (p) Interaction – could mimic mouse input to PC (p)
Compatible with Windows system	Compatible with a PC (b) Range of connectors (serial, PS/2, USB, etc.) (p)

Compatible with Internet (if appropriate)	Compatible with VRML (p)
Easy to install, plug and play.	Self contained, without several component parts or wiring (p) Easy to install (b)
Calibration for individuals	Easy to calibrate (b)
Can use with keyboard (& overlays)	Compatible with standard keyboard (basic); overlays (b)
Can use with touch screen	Compatible with touch screen (p) *Touch targets positioned below shoulder height; pointing can obscure display
Able to connect contact input switches	Connector(s) for contact input switches (p)
Compatible with voice and gesture recognition	Compatible with voice and gesture recognition (e)
Compatible with communication aid	Compatible with communication aid (e)
Ability to control 3D games	Compatible with SONY PlayStation (e)

10. Support

Design Requirements	Device Attributes
Step-by-step training to use is provided	[VE to train use of input method] [Manual/video – shows how to use input method] Training-wheels interface – step-by step guide through common tasks
Instructions: specific, simple, step-by-step, visual, demonstrational	Instruction – specific, simple, step-by-step (at user's pace); audible & visual (p) *User talks through steps (self instruction) *Introduce main concepts*
Provides a variety of support levels	Manual – set-up the system (students and teachers) (b) Maintenance manual (b)
Teacher assistance available; some users like adult attention	*Teacher available to support student (b)* Driving Instructor – dual control devices for tutor and learner (potentially peers teach each other) (e)

11. Workstation (*input device has priority over the workstation)

Design Requirements	Device Attributes
Conforms to BS for computer workstation design	Conforms to BS for computer workstation design (see design reference posture) (b)
Ergonomic design (users 7 – 19)	Ergonomic design (users 7 – 19, often smaller than peer group) (b)
Provides postural support	*Provides adequate postural support (symmetrical?) (p)*
Can stabilise/fix elbow/wrist to work surface	Facilitates fixing/stabilising of elbow/wrist (p)
Adjustable	Adjustable dimensions; safe adjustment (p)
Accessible with special chairs / walker	Accommodates special chairs (p) * cut out of surface for access
Safe to use	Will not tip when loaded (b) No undue loss of energy from body or feel cold to touch (b)
Allows teacher to view student's work	Viewing area for user and two others (p)
Accommodates necessary hardware	Sufficient space for device and other hardware (b)
Only required hardware on workstation	No distracting material on workstation (b)
Possible to adjust position of device	Ability to fix device in different positions (p)
Device can remain set-up after use	*Safe to leave device set-up (b)* *Place to store device, when not in use*
Helps focus attention on the VE	Channels attention to the VE (p)
Adjustable screen	Allows for screen position adjustment (p) *Angle of view, not exceed 40 degrees anywhere on active display area; screen at eye level; viewing distance

	at least 500mm
Helps to remove distractions	Built in carrels (p)
Access to internet (if appropriate)	Mobile (p); *positioned near network point
Primary students may require workstation not to be in classroom	[Mobile]
Of suitable size for workplace	Compact design (p)
Maintainable	Accessible for maintenance (b)
Adequate seating	Suitable seating (p)
Avoids reflections	Not exceed silky matt surface (p)

12. Workplace

Design Requirements	Device Attributes
Rap around screen	Rap around screen (e)
Conform to BS for computer environment	Conform to BS for computer use (b)
Reduce glare/reflection	Lighting – avoid glare/reflection (artificial or natural from screen); indirect light (probably best); see BS section
Appropriate position of workstation	*Select workplace free from distractions (p)* *Away from windows, doors, chatty pupils; close to teacher
Ensure clear access to workstation (cables kept clear from workstation)	Clear access to: for special chairs / walkers (b)

13. Performance

Frequency of use
- ~ 30 minute sessions
- ~ 40 students in each department, with one VE system for each department
- Therefore, if half the students use the VE system once, the input device will be used about 20 times, for 30-minute sessions, in one week

Loads to withstand (dynamic/static)
- Load exerted on device through user's hand/arm movement, i.e. push or pull force
- Impact load if device is knocked from desk height to the floor

Buttons
- *Displacement force – 0.5N to 1.5N until actuation*
- *Button displacement – kinaesthetic feedback, minimum displacement 0.5mm, maximum 6mm*
- *Shape – to assist finger positioning and button actuation*

Further requirements
- *Surface temperature of device – not > 40 degrees C*
- *Signal speed – feed forward signal from input device to system should occur within 20 ms*

Joystick
- *Actuation force – to displace finger-operated joystick, 0.05 to 1.1 N*
- *Displacement – hand operated joystick, not exceed 45 degrees in left and right directions, 30 degrees forward and 15 degrees backward (toward user)*

14. Target Price

- Needs to be affordable for special schools
- A rough price range would be between £50 - £100

15. Production Requirements

Product size and weight targets

- Compact: to fit on desk in front of computer
- Of suitable weight and size to be carried easily by older student or teacher

Manufacturing constraints and preferences
- Materials: cost effective, durable, non-hazardous, robust, comfortable for interface
- Manufacturing processes: low cost, minimum necessary, utilise Nottingham Trent University manufacturing facilities, parts bought-in or manufactured outside university
- Assembly: minimal parts and fixtures, accurate part mouldings, simple mechanical and electronic design

16. Life in Service Requirements

- Target life in service: ~ 5 years
- Installation: technical staff, follow step-by-step instruction manual
- Device information: see section on Support
- Reliability/durability: reliable mechanical and electronic design, durable materials

Maintenance requirements
- Wipe-proof surface
- Parts details given in installation manual
- Parts can be replaced by technical staff or device sent to manufacturer for repair

Disposal/recycling requirements
- Can be disposed of in domestic waist or
- Send to manufacturer to reuse device parts

17. Conformance Requirements

Device compatibility requirements
- Compatible with VE software
- Compatible with a PC

Safety / device liability requirements
- Conform to health and safety standards

Testing requirements
- User-based assessment will be conducted using suitable device prototype(s)

Industry standards
- Conforms to BS for computer Interface devices (ISO CD 9241-9, 1996)
- Conforms to BS for computer workstation design (ISO DIS 9241-5, 1995)
- Conform to BS for computer use environment (ISO DIS 9241-6)

Appendix I

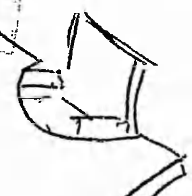
- Visual Design Specification
- Sketchbook 1
- Sketchbook 2

FIND AND SEARCH

Design of Input Device for VE tasks for users with learning difficulties

Visual Design Specification

- Modern styling – (b) (Require mood, theme, lifestyle boards) from books
  - bit like I-mac
  - nice colours
- Ergonomic design – (b)
  - see references.
- For wheelchair users. (b) or (special chair users)
  - At table/desk. Can access device Reach easily



- Neutral working posture – (P) (see standard)
  - May need adjustable workstation / surface height (up/down)

OR

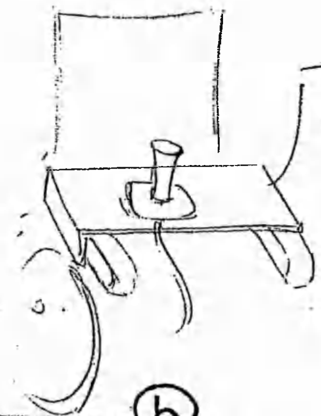


Table to use device on.

Don't have to grip (P)

· It can grip you ·

user's hand slides in here, can tighten strap for security ... etc.

(b)

for Left + Right handed users

or both together.

How will user hold the input device?

Contact?

No Fine finger operation (P)

- buttons easily accessible.

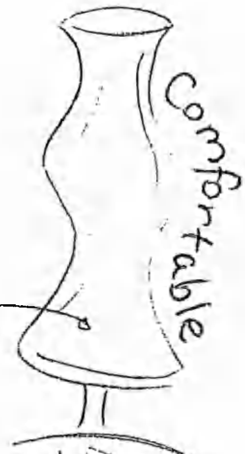
Muscle support (P)

research muscle supports

what is a comfortable form

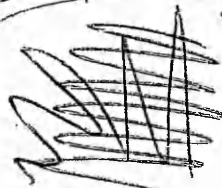
- Comfortable form (P)
- Comfortable interface | Material | (P)

- mmm ... soft and squigy
nice to touch hand against
warm.
- Material research required



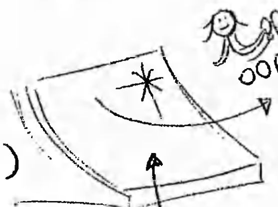
Comfortable

Surface (P)



Not too rough. (abrasive)

- ouch! too rough.



oops - it's slippy

nice to touch or hold

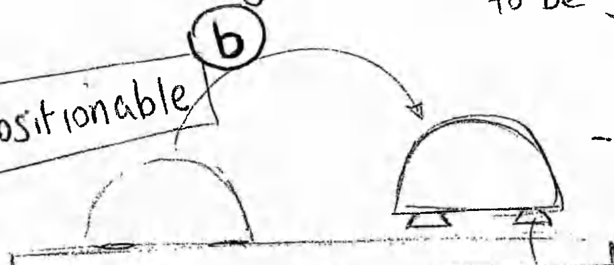
not too smooth to be Slippery

what materials are available?

touch a few devices in PC world, Dixons, currys etc

Look in IKEA for design inspiration

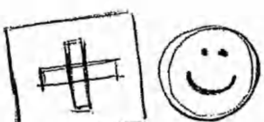
Repositionable (b)



- Without tools

- how can you reposition the device?

wee Suckers



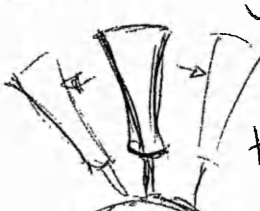
✓ well done

- Conforms to health + Safety standards. - (b)

conforming to BS, so should conform to H+S too.

- Avoid STATIC muscle loading (muscle support will help, try to ensure dynamic use).

(P) - dynamic operation



Hand position is changing ✓

- Also - operation involves postural change

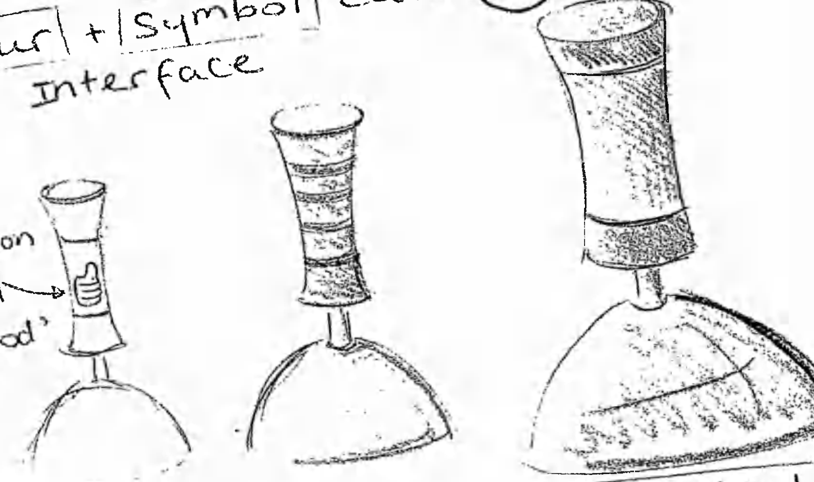
?

(b)

No Raised parts

No sharp edges or corners

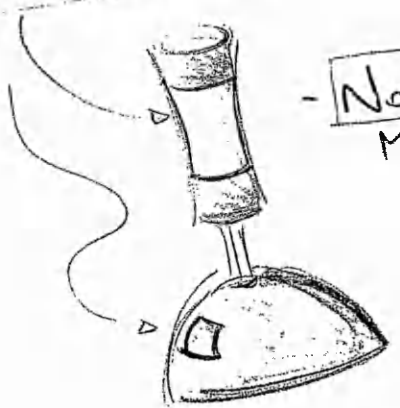
Colour + Symbol cues (P)
to Interface



- need to make final desision on what functions the device can be used for

Essential details / components highlighted (P)

form indicates function



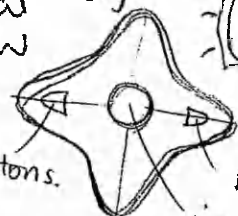
- Not Cluttered (P)
Minimum detail.

How will form indicate navigation control?

Form indicated navigation control.

(P) - Aerial view e.g.

Research

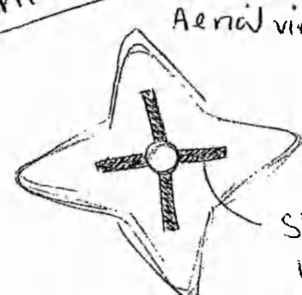


- products that indicate navigation control.
(i.e plane controls)

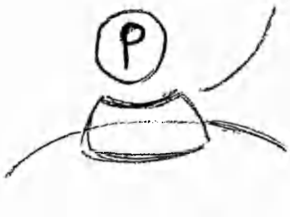
- Form indicates how navigation control is achieved -

Familiar with steering wheel concept.

Aerial view



- Research this requirement.



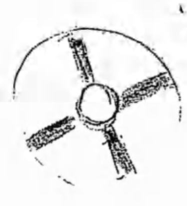
Button's form invites user to actuate it.
(button details)

Colour + Symbol cues
to function

(P)

- aerial view
i.e symbol

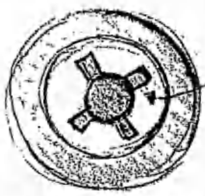
Colour



Modifiable operation difficulty P

- adjustable degrees of freedom P (in software)
- guides or no guides.

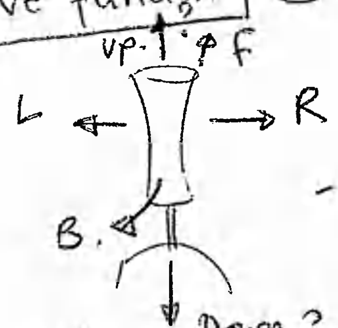
i.e.



Aerial view
guide for easier device direction finding

No excess functions P

One user Action = one VE function P



Twist to turn left and right. May have to compromise this requirement with minimal functions ??

Obvious

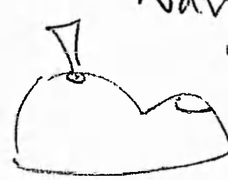
Movements are specific P

- can use guides for this - or internal mechanics.

1st - turn Left, turn right, move forward + back
2nd - look up + down, move left and right.
Also - jump etc - games control.

All functions in one P device / or two ? - must try out.

OR

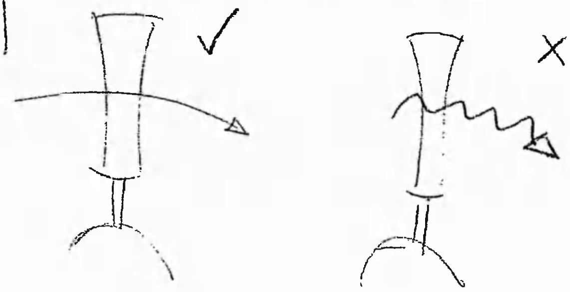


1 device or 2 ?

Provides necessary assistance (P)

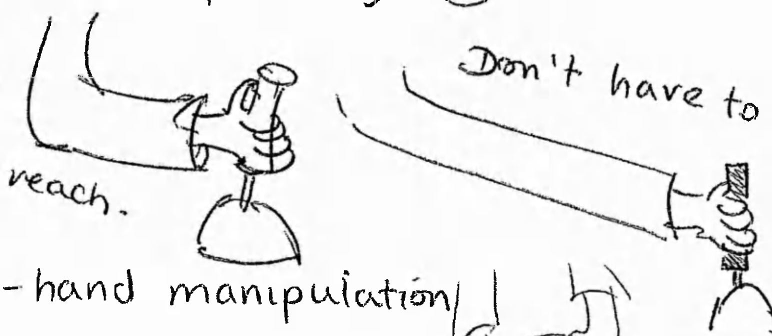
- What is necessary? - research further

Smooth operation (b)



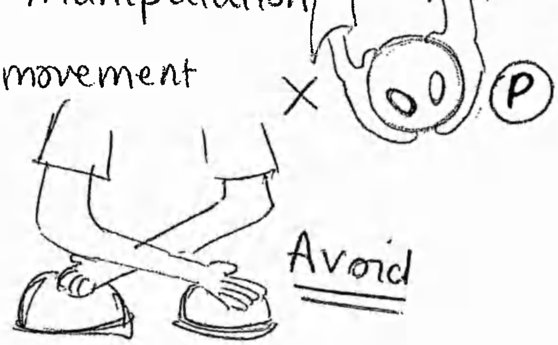
Calibration - damp out unintentional movement. (software) (e)

Reachable (b) - easy to reach.

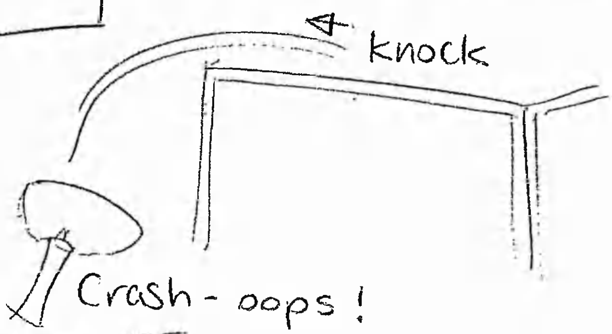


Don't have to stretch.

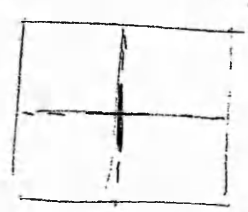
- minimal in-hand manipulation
- Avoid cross-lateral movement (initially) (P)



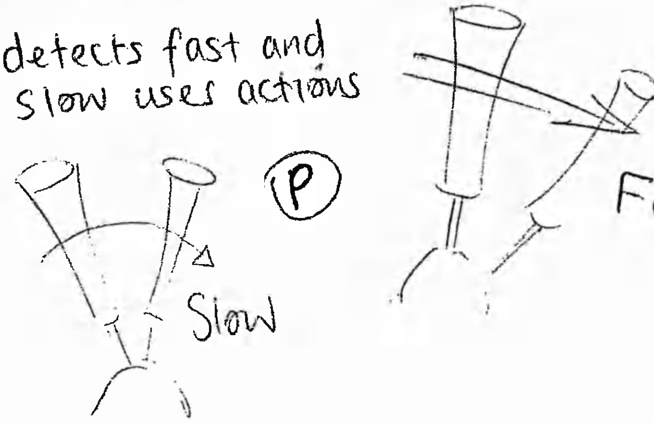
Robust (b) construction



- Calibrate balance (software). (P)



- detects fast and slow users actions (P)



No time limit (P)

Movements

Navigation

① Forward / Back • Left / Right turn ① primary movements. (b)

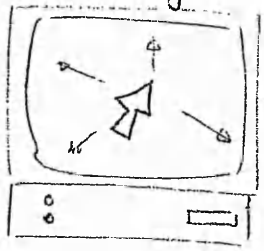
② Look up and down • Left / right movement. ② Secondary movements (P)

Fine movement function (mechanics) (P)

Interaction + (b) up / down / Left and right (position cursor / object)

Cause interaction (b)

button



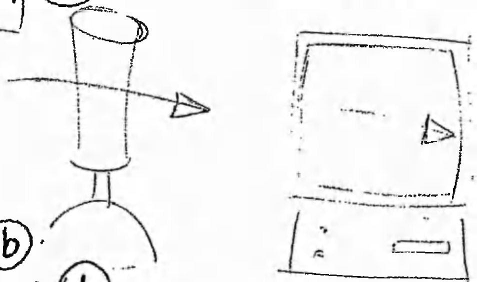
- etc.

+ fine movement function ?

(Drag and drop).
2D software.

- Configurable device controls -
(P) (in software) - configure for control of different functions for different VEs.

Adjustable gain (P)



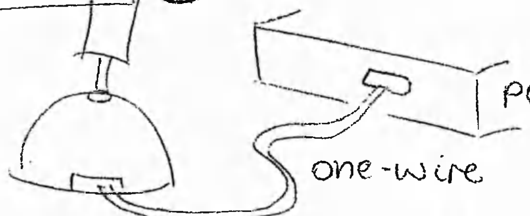
Compatible

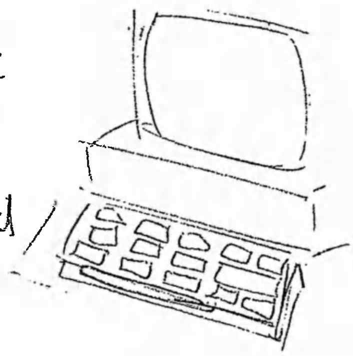
- VE software (b)
- PC (connectors). (b)

- Self-contained (P) -

Easy to install (b)

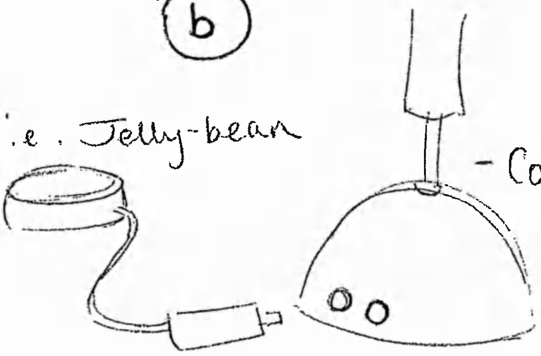
- could mimic joystick and mouse input.





- Compatible with standard keyboard
(b)

i.e. Jelly-bean



- Connector(s) for contact input switches.
(P)

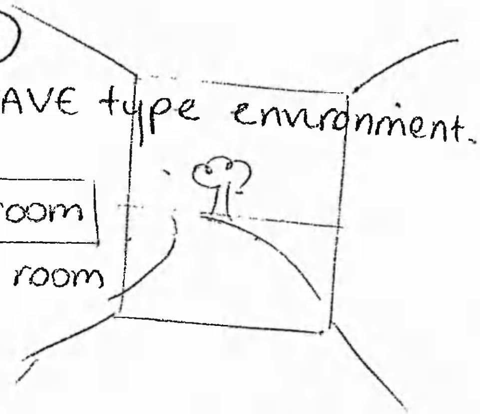
Workplace

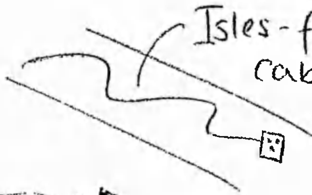
- BStandards. (b)
- Avoid glare

- indirect light is best.
- free from distractions (if possible)
- clear access (b)
  - for special chairs / walkers.

Rap around screen - or CAVE type environment. (e)

VE room
- interactive room

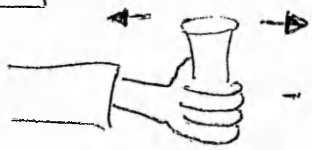




Isles - free from cables.

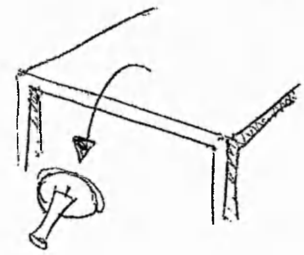
Loads

(1)



- push or pull force.

(2)

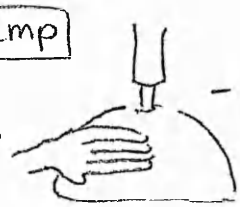


Impact load, of fall / knock.

Button

- Shaped to assist finger positioning and button actuation

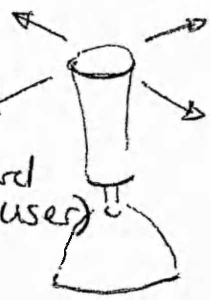
Surface temp



ouch!

- not > 40 degrees C

Displacement



< 30° forward

< 15° backward (towards user)

< 45° Left and right.

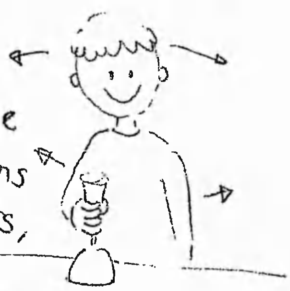
Design requirements from BS

Effective feedback

- immediate indication that device is reacting to user actuation

Possibly visual - lights up / sound etc.

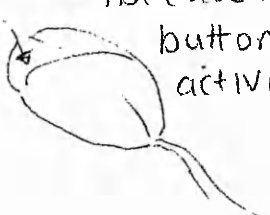
Upper extremity and head posture



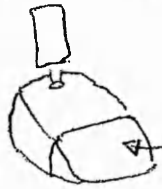
- not require undue deviations of hand, fingers, arm, shoulder and head from respective neutral positions

Inadvertent pointer movement

- not caused by button activation

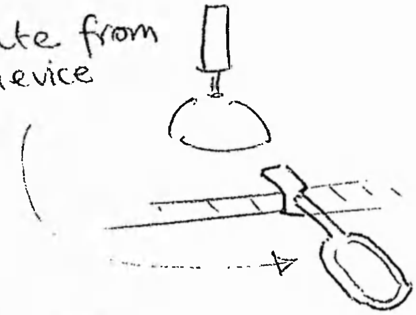


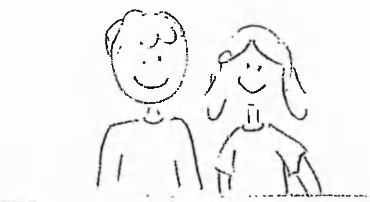
Muscle support



incorporated into design of device

- Seperate from the device





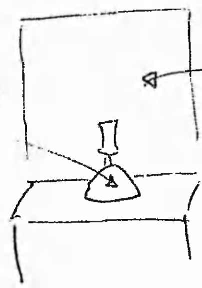
- Shared workstations ?

Lighting

Work environment.

Small objects

- more highly saturated tints



Large surfaces / backgroun
colour - pale / low satu
(pastel shade

Grasp - variable grasp / not require pincer grasp (research)
- wrist flexion - palmar grasp (?)
- wrist f + finger extension - finger surface grasp (?)

Colour deficiency - don't use colour as only cue, use symbol too - Makaton

Universal design
- where possible, consider design for all (inclusive)

Environmentally friendly
- materials
- manufacturing

Sketchbook 1

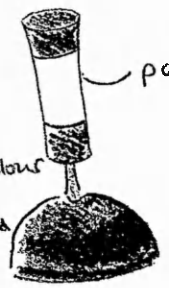
Visual cues

- Colour cue to interface - colour not great cue as some users may have colour deficiency,

So shading would be good.

if contrast in colours sufficient then non-colour deficient and colour deficient will benefit.

For example.



pale colour (pastel shade)

deep colour dusk

In this example the shaded area indicates where to hold the interface

OR opposite way around.

A pattern could be used

- these indications are helping user to know how to hold, contact the device

A symbol cue could be a Makaton symbol - for example -

Might indicate that user puts hand in this position.

- Form indicates function - and device orientation

Research - products who's form indicates function
- how the input device can depict it's function, (this should help with motor planning)

- Further visual cues to function
- Form indicates interface
- Visual field ?
- Material research - feel some existing products
- Muscle support - research existing supports
- How to interface ?
- Wheelchair / special chair users access
- Neutral working position

- Relevant feedback visual, auditory, haptic
- Movement in VE same as user actions
- adjustable d o f configurable controls
- one user action = one VE function
- No excess functions
- 1 or 2 devices ?
- not distracting

Games - Not Playstation or Nintendo at moment.
(could look at how input works)

- control 3D games on PC
(how are 3D games on PC controlled? probably with joystick)
- only simple games, with simple controls
(Research at PC world).
- what controls would be required?

1 Click, double Click

Work Station or not?
Start initially with ID design - think about WStation later

1 device or 2? - need to try out

Grasps -

2nd time through design specification 27/03/01

Need - Mood, theme and lifestyle boards

Lifestyle - explore range of users product should appeal to
- images of target users (personal + social values

Mood - sentiment, feeling, emotion product engenders when first seen

Theme - Images that convey target mood (from diverse market sectors too)
- Explore styling features that have succeeded
- Inspiration, rich source of visual forms.

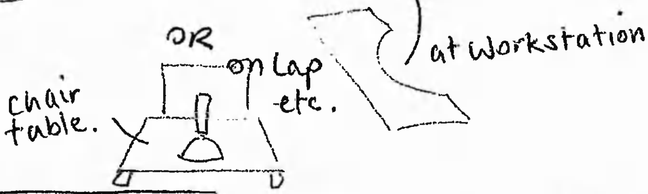
- Styling.

Modern styling - I-Mac

Ergonomic design - neutral working posture.

Special chair users - access

OR



Interface - don't have to grip
Palmar + finger surface grasps (not require pincer grasp)

Left + Right hand

No fine finger operation

- buttons easily accessible

Repositionable - without tools.

Buttons - good actuation resistance

Can be fixed to workstation

Minimum detail - not cluttered

Form indicates function
- navigation and interaction

- Research - products that indicate functio

form indicates orientation

Relevant feedback
- visual, auditory haptic

Movement in VE same as users actions

Function

VE control - investigate methods of VE control
how are VEs currently controlled?
Joystick and mouse or another type of device?

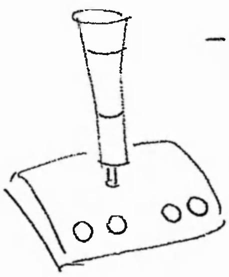
2D control - really need to mimic a mouse input
Hence to control 3D + 2D use mouse input
for interaction and joystick input for navigation

Alternative VE controls - HMD
Spaceball - 6 dof etc

Keep it simple

- A control pad

can configure
inputs to be
for navigation
and interaction



- I need some help to be able
to make this decision

- I want to keep the design as simple
as possible, and for it to be easy
to install, easily compatible and
configurable - so - I think it would
be best to mimic joystick and
mouse input to the PC as these
already work and are recognised.

So - do I need to research
alternative control devices
to Virtual environments?
- no - because they are all individual; with their individual drivers
- so leave this part of research.

So try to mimic joystick and mouse input to PC.

Mouse

- general mouse movement
causing cursor control
and using button for interaction purposes.
- Directional control of cursor
- Interaction with item /object etc
- Possibly drag and drop etc.

Joystick

- navigation control through 3D environment.

Primary - forward / back movement.
turn left + right.

Secondary - look up and down
- move left and right.

Additional - jump, hard left /right etc?
Accelerate, crouch etc

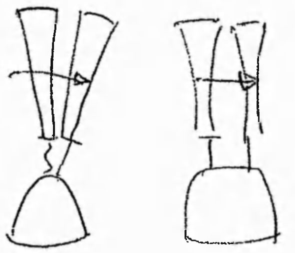
functions possibly configurable and as add on to device.

Keep minimal
Add on extra functions.

What would be an exciting or unusual way to cause this forward movement?

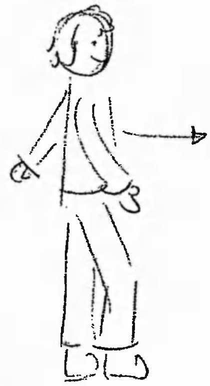
- Speach "forward."
- Sound.

Hence - thus far.



bend translate

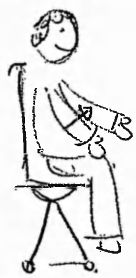
- Moving something forward.



Walking forward.

(Gross motor - not ~~fin~~ sitting down)

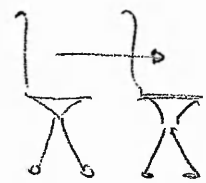
X



Moving body part forward.

(perhaps too abstract).

Gyroscope type of idea.



Shifting body forward

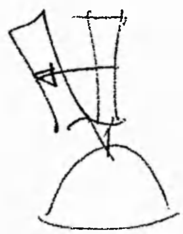
- perhaps on seat.

X

- Can use hands - so use hands -

Backward - using hands - pull something back

- as this happens user's body will also go back a bit.



Turn left - look left and right X you would actually turn left on the spot or whilst moving forward.

Currently - joystick

turn left.

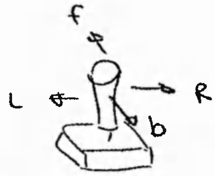
- in reality or directly speaking this would result in the world tilting left not turning left.

More directly turning left.

twisting something to the left.

How is a powered wheelchair controlled?

- Joystick is used
- the operation is learned - so perhaps don't need to think too literally about the movements - just make sure as simple and understandable as possible.



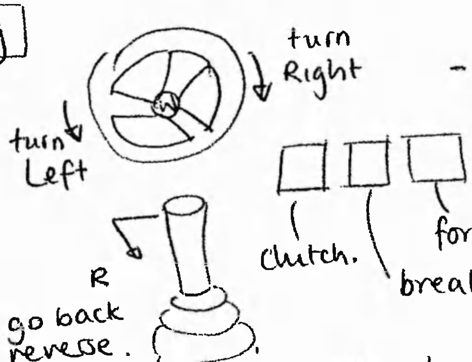
this seems to work OK
the users are able to learn the operation.

- Consider the situations - walking, driving, cycling, flying

Walking - turn left / turn right. on spot
More forward or backward.
Occasionally step sideways
and look up and down + left + right (covered by turn L+R)

Driving

- Wheel

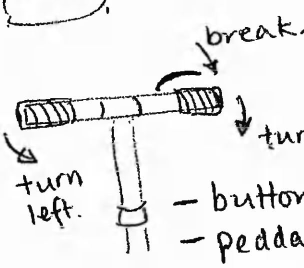


- to simulate.
- have a wheel for left + right turning
a button to accelerate and a button to break + possibly a button for backwards.

OR tilt wheel forwards to accelerate and towards you to break. or to go backwards.

Cycling -

- handle bars



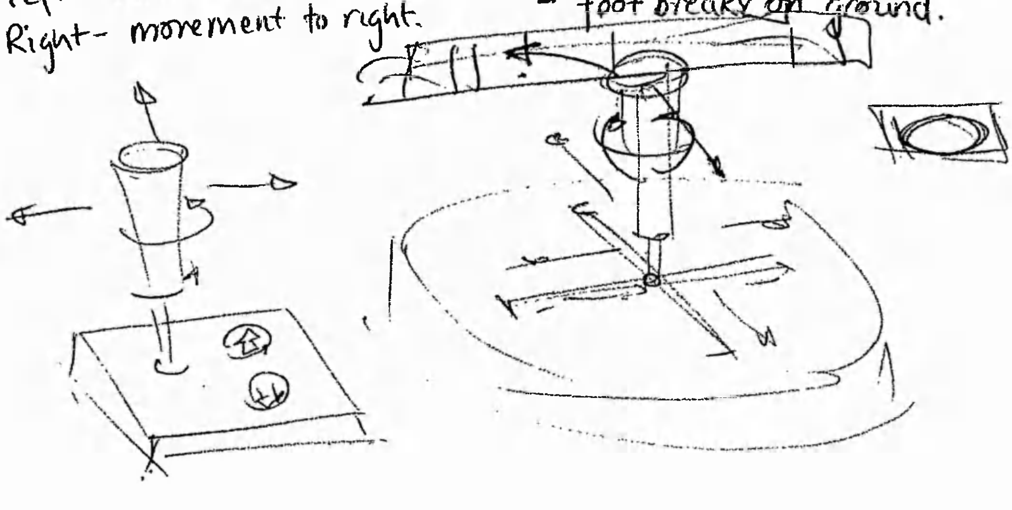
- button to brake
- peddals for forwards or button
or tilt handle bars forwards.

flying

- pull back - up
- push forward - go down
- left - movement to left
- Right - movement to right.

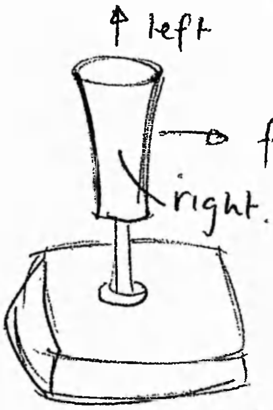
Throttle - pull back increase speed
push forward decrease speed.

- foot breaks on ground.



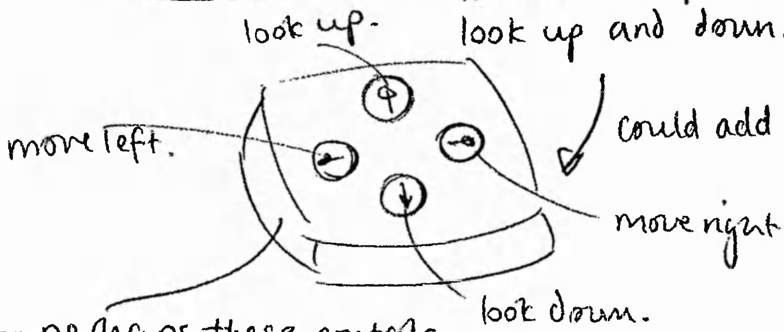
As little functions as possible
and one VE function = One user action.

Minimum functions - forward.
turn left and right.



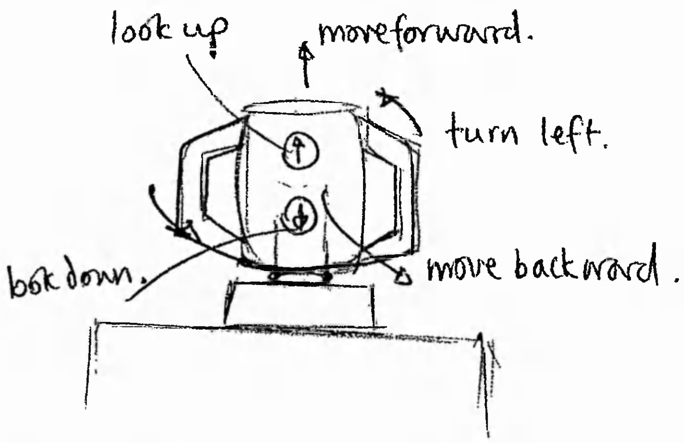
- not direct - but simple

- then - how do you add translate left + right + look up and down.



could add a control pad.

- perhaps these controls could be configured for different functions for different VEs.



- Would it be possible to adapt the device to suit any kind of vehical or transport ?

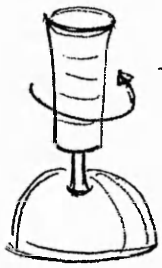
- Would it be worth while doing this ?

Keep it simple
- forward movement
- left/right turn
} Primary

- Move back
- Move left + right
- look up and down
} secondary.

literally - direct movement

(1)

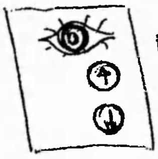


twist left and right to turn

translate forward to move forward.

(2) Add more functions

Move left + right - translate L+R
look up + down - bend forward and back
Move back - translate back.

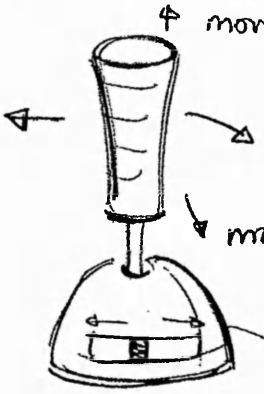


look up and down - buttons.

OR more similar to joystick functions

move forward

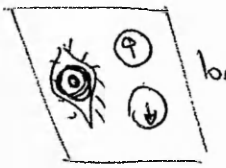
turn left.



turn right

move backward.

move left + right ?



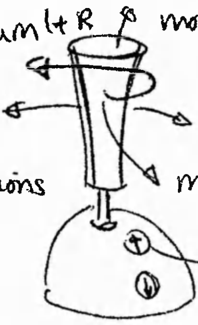
look up and down.

OR - mixture of both

turn L+R

move forward.

move left



move right

move back

look up and down.

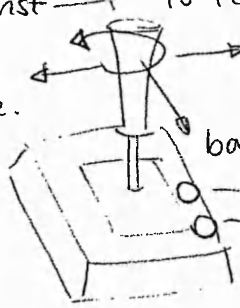
- could possibly lock functions to make device easier for some users.

How many joystick functions needed - ?
- additional buttons to configure

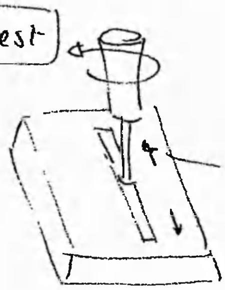
So far -
move forward / back
turn left / right.
move left + right
look up and down.
} additional
- Jump
- hard turn
- fire ? etc

Concepts so far

① - Direct ~~manipulation~~ mapping.



Simplest



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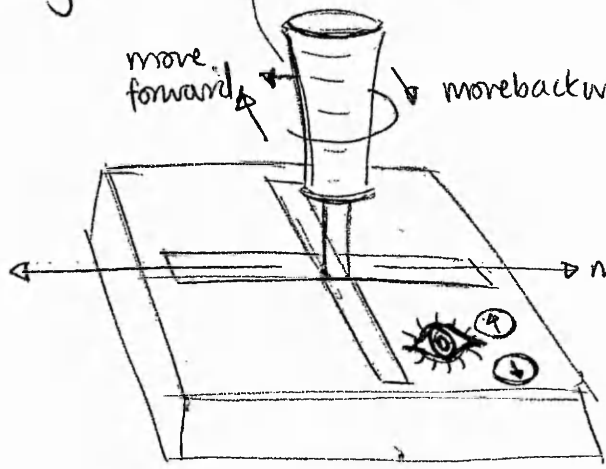
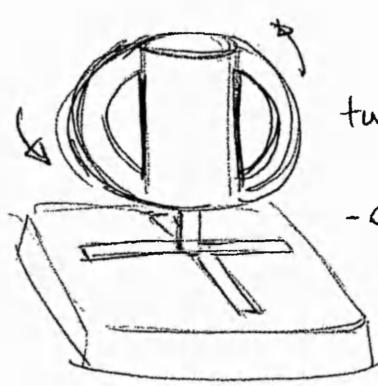
① Direct mapping

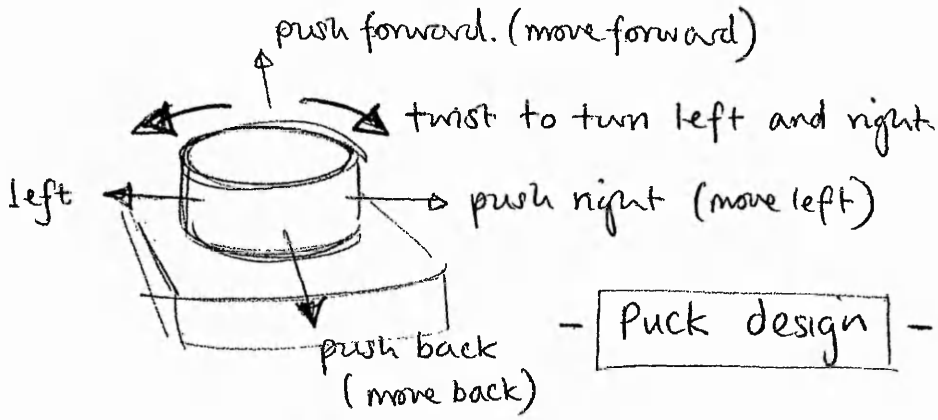


- up and down
① pull back - look up
push forward - look down
OR buttons and look symbol.

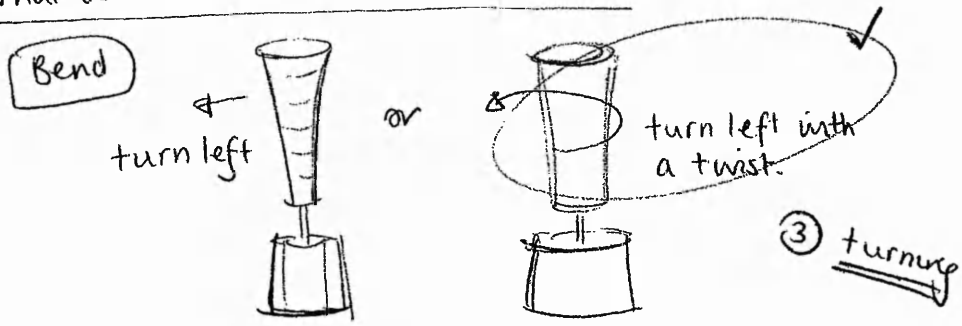
② Direct mapping



- Other functions as above.

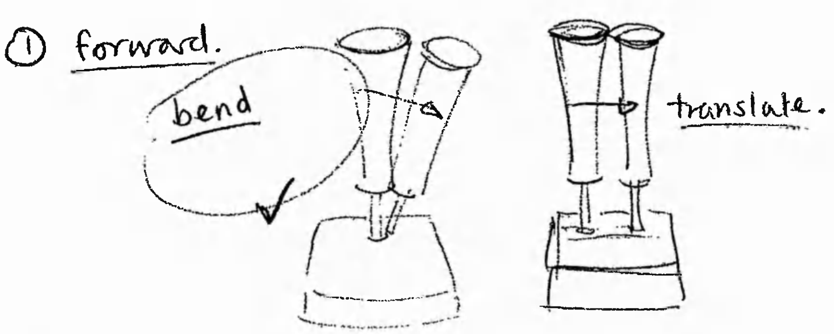


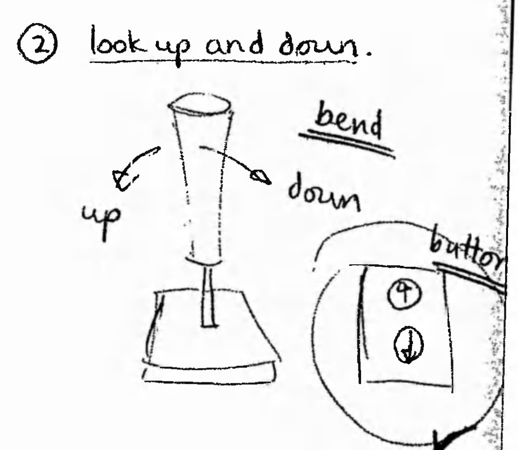
What do the children understand best?

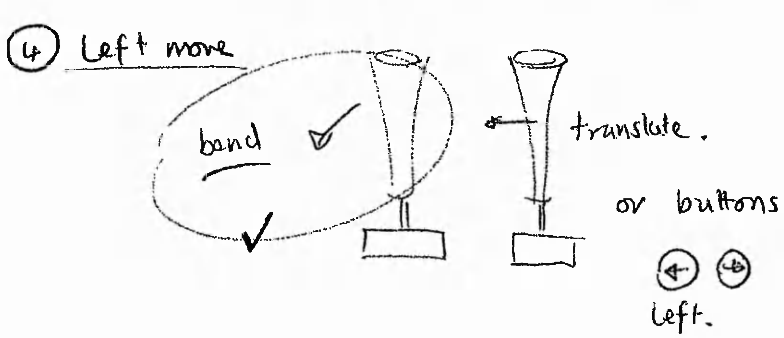


more left and right are additional movements
- as - look up and down.

- Need to be able to turn around in a 3D world.
Need - forward + left/right turn initially
Should forward be - bend or translate ?
Should look up/down be - buttons or bend?
Should turning be - bend or twist?
Should left move be - bend or translate ?





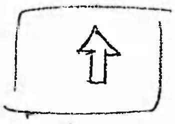


Interaction

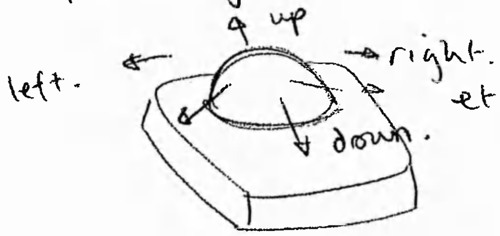
- direct interaction → touch-screen

- Alternative - control cursor -

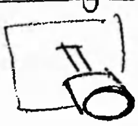
up / down
left / right
diagonal
} mimic mouse input.



Either
up / down
left and right or more directions available.

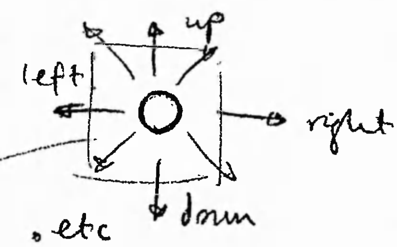


etc. ← Trackball design



OR Joystick

Button for interaction



OR touch sensitive screen.

Joystick may be easier to control than tracker ball.

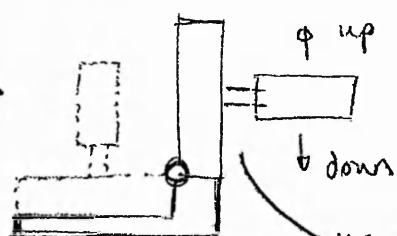
- perhaps vertical so translates to screen better than on flat.

move finger along surface (more abstract concept).

So → two joysticks may be required. or one joystick + one track ball.

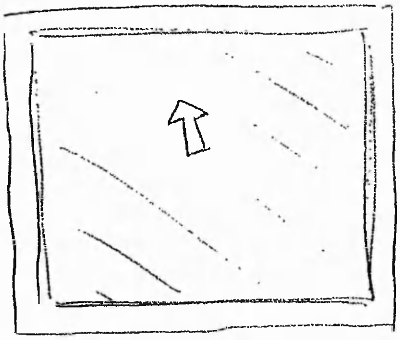
- Possible to have one for navigation + interaction and to be able to switch between both ?
  - with one switch

horizontal position - navigation



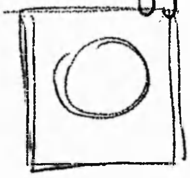
vertical position - interaction.

*
- May be a bit of hassel to keep pushing up and down.

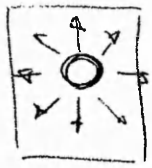


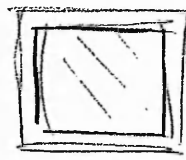
up, down
left, right.
etc.

- direct mapping, as close as possible
not a gyroscope idea - too abstract. - i.e holding in hand.



trackball
or joystick

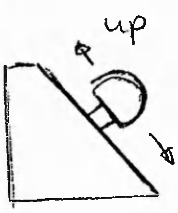




touch
sensitive screen / pad.

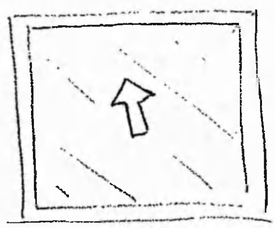
- directly touching screen - using touch screen monitor.
- or pointer to touch screen monitor.

- Think about how these ideas could be implemented. -



etc, etc

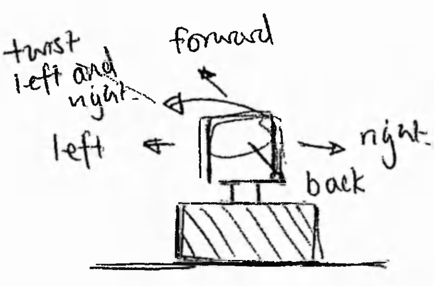
on a slant.



up, down, left right etc.

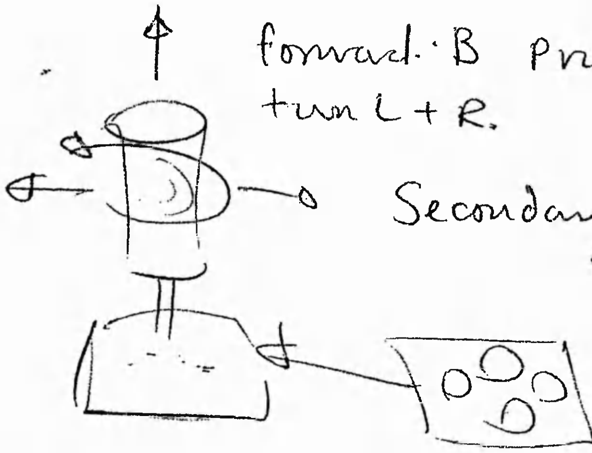
- Makes more sense if in vertical plane
- will student's transfer if in horizontal plane

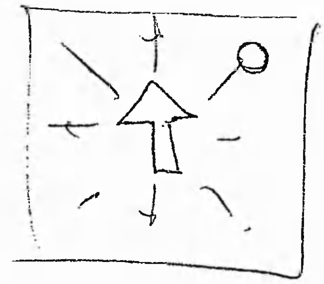
✓ I think so - and those who can't could use a touch screen with a pointer or glove to protect the screen.



- how will interaction + navigation link together?

Explaining navigation and interaction.

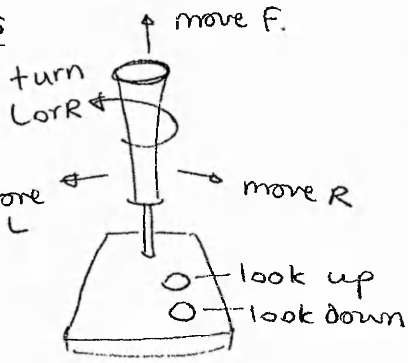




- Decisions from these design ideas -

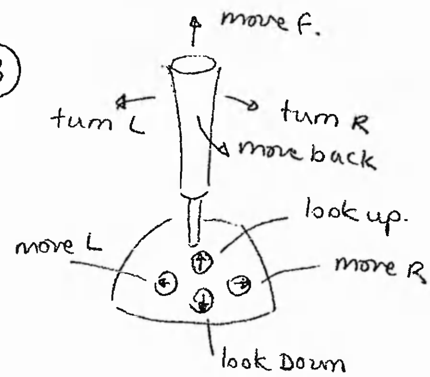
Tests

navigation



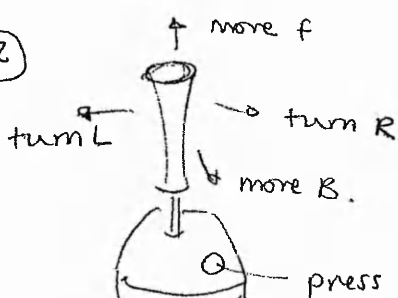
(1)

- does student understand twist / turn.



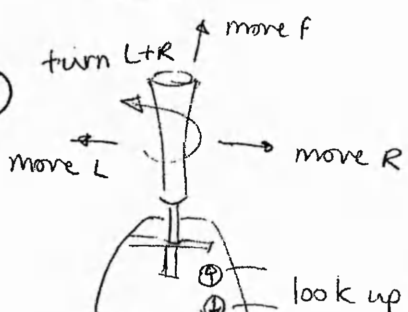
(3)

(2)



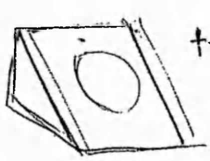
- look up/down
- move L and Right.

(4)



- if bending done then ×
no either could do two in (1).

Interaction



Which is easier ?

- Could mount a trackball + joystick at a slant and test out these concepts.

Tremor

☆ Tremor minimised if movements - in horizontal plane
- in lateral (L-R) direction
- with forearm pivoted at elbow.

Tremor greatest during in-out arm movement in vertical plane
(may not directly relate to users in my group)

To help reduce tremor
- use of visual reference
- support of body in general and body member involved.
- hand position - less tremor if hand within 8" above or below ♡ level.
- friction - adding enough resistance to movement to counteract in part the energy of vibrations of body member.

Control Design

Little manual effort - push-buttons, toggle switches, small hand-levers, rotating and bar knobs

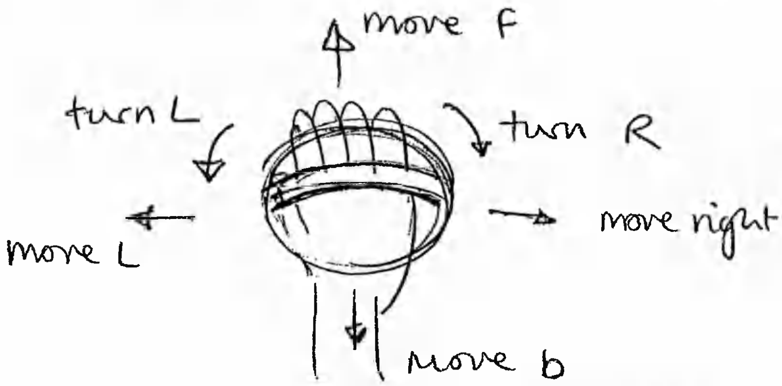
Hand-operated controls -
- between elbow + shoulder height.

MAIN POINTS to FOCUS ON

- Don't have to grip
- Palmar and finger surface grasp
- No fine finger operation
- Muscle support.
- May tire easily / quickly
- Clumsy pen grip
- Using two hands
- Slight hand / arm tremor
- Quite straight arm
- Poor MDC
- Joystick on lap
- Motor planning difficulties.
- Motor tension
- Limited wrist movement.
- Wrist dip
- Short fingers
- weak grasp - 1
- neutral operation position
- Clawed and tense fingers
- spread and uncontrolled fingers
- finger raised - stuck out
- tight grip
- unsteady arm movement.
- not fully stretch right arm
- Co-ordination difficulties
- unsteady control of device
- Slightly jerky movements
- not gripping completely round side
- finger stuck out when gripping
- not using all fingers to grip
- CP in R hand and arm.

Internet research

- use whole hand
- hand bent upwards (dorsal flexion)
- horizontal moves better than vertical
- within arc of 45-50° to each side
- exert force ⊥ to axis of cylindrical ha
- Wrist in neutral position
- Pivot point under pt at which wrist is rested

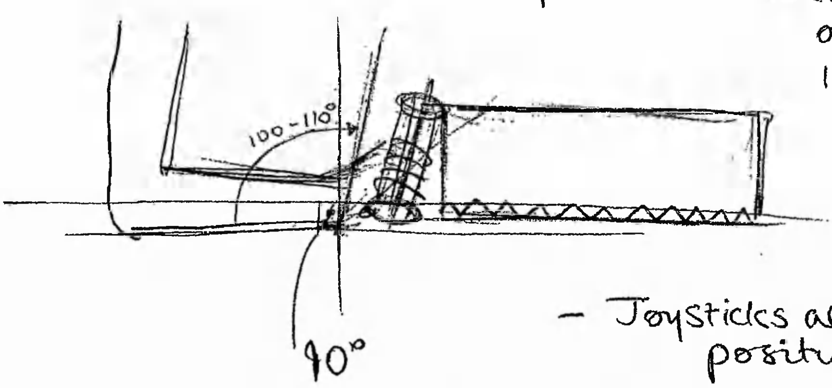


Note pivot pt under pt at which wrist wrests

- which angle most suitable?
- wrist - in neutral position - what is neutral position?

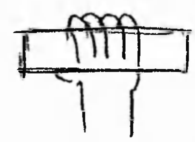
When wrist in neutral position, long axis of cylindrical handle makes angle of 100-110 degrees to axis of forearm.

Wrist in neutral position



- could be holding horizontally or vertically and be in neutral position

i.e



- Joysticks are in vertical position
- Mouse operates in horizontal position.

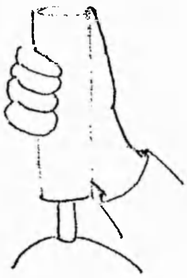
Vertical - wrist twisted to the side. (on side)

Horizontal - wrist flat (facing table etc)

- Wrist should be in neutral position.
- hand bent upwards
- Within arc of 45 - 50° to each side
- horizontal moves better than vertical
- use whole hand (if possible)

So, all students should be able to use a palmar grip
- but some may be weaker than others.

- Palmar grip
Close fingers around object, but not thumb



Squishy thing

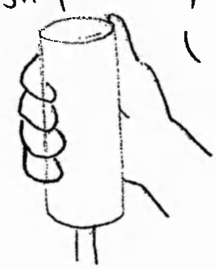
Glove - student puts hand in a glove - this is the interface

- Student grips a squishy thing -

Remember - neutral wrist position

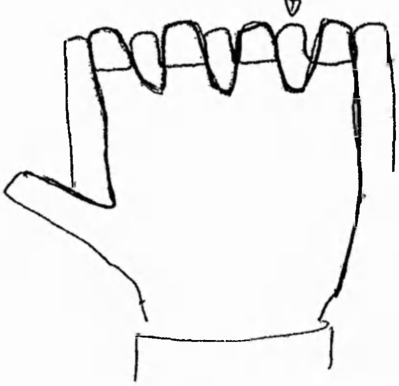
Student grips round flatter interface - more 'puck' shape.

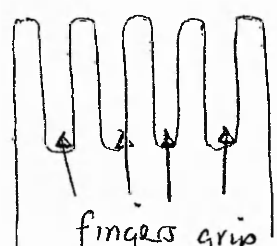
Stick - shaft interface



but material makes it easier to hold for student.

hand grip interface





fingers grip between pegs of interface.
- may give a secure grip

hand (exept thumb) slots through to grip

Sketchbook 2

Students are able to grip - but some weak grip and some don't find it very easy

So - looking for Simple ways to hold or grip things OR Alternatively the device will grip the student.

Simple Interface Required.

- Simple + Comfortable + obvious + stable.

- Perhaps go to mothercare as grips should be easy there as for babies

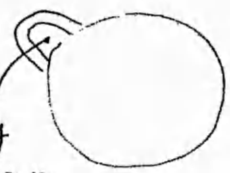
- also - house hold products
- need some inspiration

- perhaps option of it gripping you instead.

- washable covers - material.
- Foam material - for baths etc
- Baby basics Heinz (from 18 months) - 1st cutlery set.
- Soft shaped handles for gripping
- finger and thumb rests to help hold

- flexisoft material
- made from safe durable material.

Weaning set.



easy grip - no slip.

- Boots - soft easy grip fork and spoon. (from 9 months.)
- Special contours and ridges improve grip and control.
- Soft, pliable handle coverings to cushion small hands.

- First feeding spoons. from 7 months.
  - finger + thumb rests.
  - soft shaped handles for me to grip.

- Boots training cutlery set (from 3 years)
- Ergonomically designed chunky handles for small hands to h

- Three Steps trainer cup - easy grip handles, specially angled for me to hold.

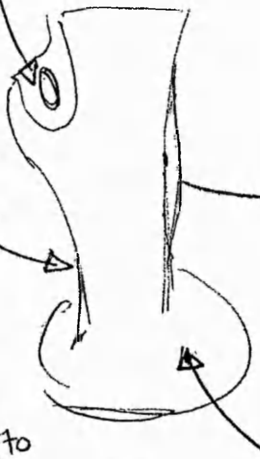
made of flexisoft.

Tommee Tippee.

- 

- soft handles for easy grip.

Specially shaped for tiny hands to hold.



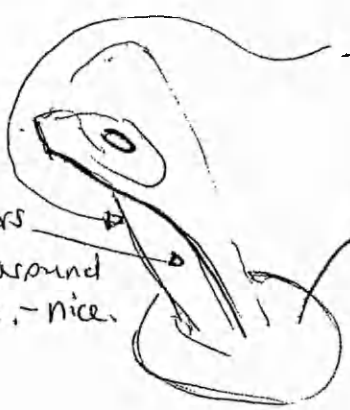
- like the shaping alot on this
- just avoid thumb button.
+ would need to be able to turn around for left handers.

Logitech Wingman - nice shaft shaping not quite as nice at Gravis.

- nice wrist rest - could be a bit larger

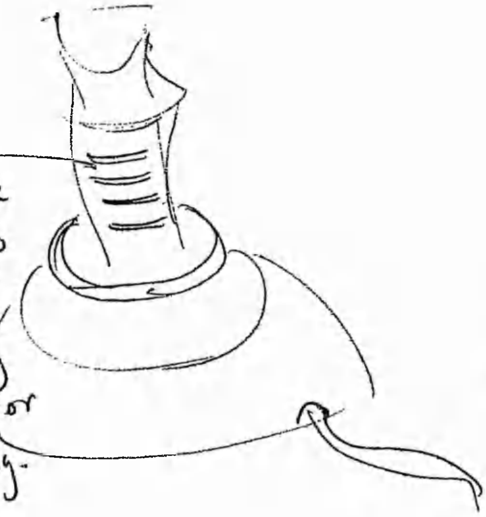
Side-view of Gravis

Left-side view



Microsoft

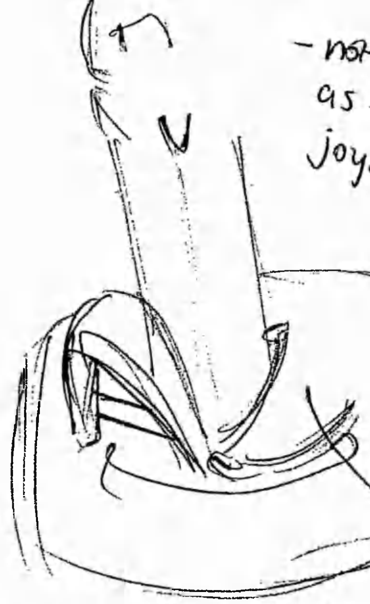
back of.



riges

- quite nice effect to feel but not drastically different or amazing.

Saitek Cyborg 2000.



- not as comfortable as the more contoured joysticks.

Wrist rest.

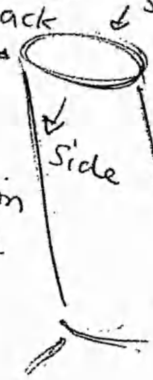
- it is comfortable to be able to rest your thumb as is other joysticks

* note back

side.

Side

front.

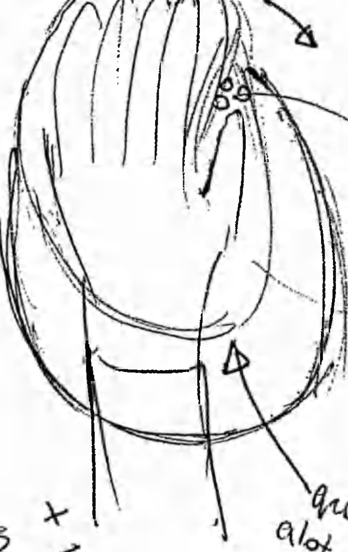


Shape of Shaft section is more like this than round

Something new

Microsoft sidewinder

buttons near finger tips.



more buttons by your thumb.

top part twists left + Right on bottom part.

- can also push in all directions to the sides

quite alot of room to rest your wrist too

+ wrist almost in neutral position I think.

☆

- This is exactly the movements I was thinking of - but would need to look at gripping changes as this design is like a mouse and you really need your thumb to get a good grip.

Then, trip to PC World

- Joystick with nicely shaped shafts.
- Mouse designs - difficult to hold without thumb use
- Microsoft Sidewinder - similar function to what I was thinking for the new input device.

— TWISTING and MOVING —

- need to investigate ideas, where gripping not involved.
- need to look at form indicating function.
- need to touch + feel + pick up household products for more ideas
- Storyboards + moodboards
- Muscle supports
- Materials.
- Catalogues + pictures of products.
- Stick close to ergonomics and British Standards.
    - Design reference posture
    - Neutral operation position
      avoid RSI etc.
    - Dynamic - not static operation
    - All Interface + functional assistance pts

Currys

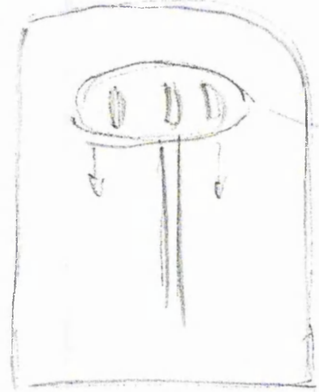
Siemens C35 - mobile phone -

Slight curve on side for hand shape.

- handles.
  Palmar grip possible if handle is thin enough.
- Plastic has more resistance than metal handle. -
- Combination of seethrough plastic + opaque is nice - Sony CD
- Aiwa CD Radio Cassette - radio cassette-corder.
  - ridges in plastic handle form pattern - looks quite nice.
- rounded edges to handles are nicer.

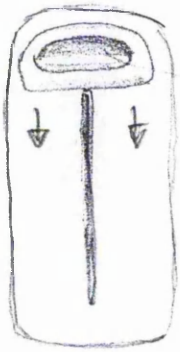
Breville Toaster - 34.95

- ridges help user to grip the part that is interfaced - need to avoid pressure pts though.



ridges on part to put toast down does make part more interesting to touch

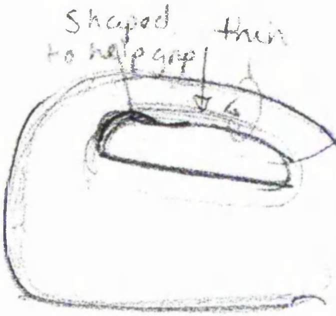
Morphy Richards 29.95
- toaster



Scoop out also helps with function of pushing down - + with getting a grip

- enough scoop to get good grip.

Breville hand mixer - 17.95

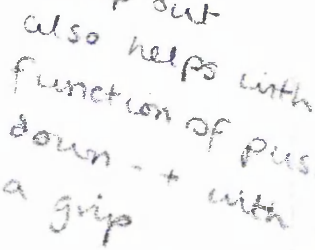


- smooth corners but slippy material.
- can grip without thumb
sprayed metal look finish (slippy)

Irons

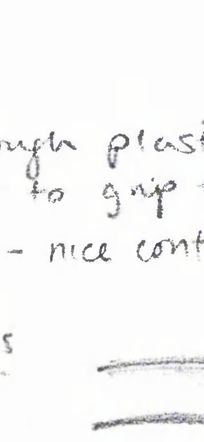
- see through plastic less slippy to grip than normal opaque plastic
- again - nice contrast between opaque + transparent plastic.

Some irons



almost symmetric section or shape

Others



curve on inside surface of handle.

this seems to be actually - not much difference in comfort or grip with these shapes.

Morphy Richards - Comf: - grip.

rubber

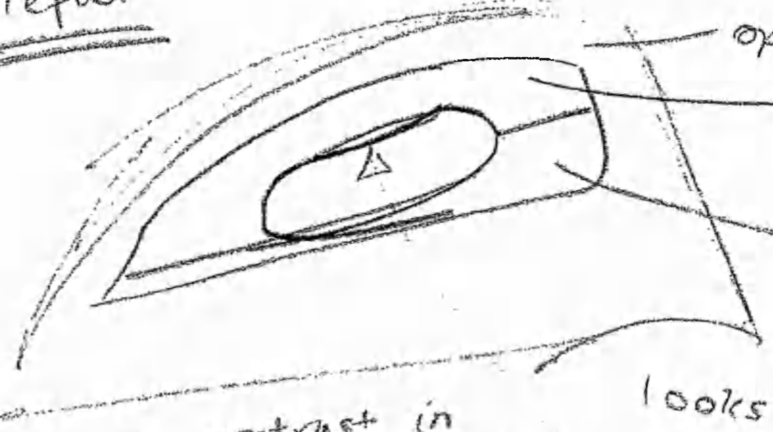
Soft grip handle - for comfortable use

- can see that rubber gets worn and dirty + then doesn't look as good.

- looks like this rubber could get mucky + ruined more easily than plastic - how easy to wash too?

- is quite comfy though -

Tefal.



opaque shiny plastic.

matt plastic

transparent plastic

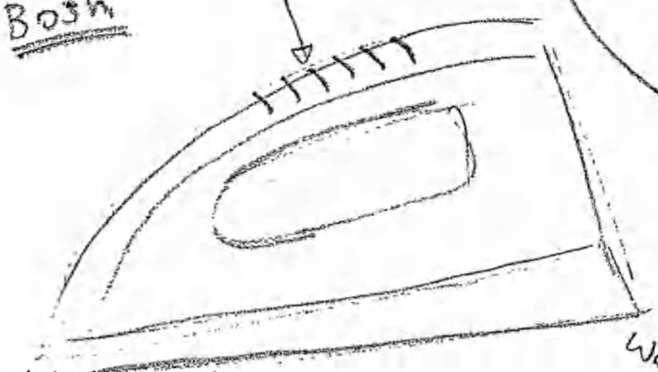
- Like contrast in different plastics.

looks very streamline.

quite like this shaped handle too, but doesn't help significantly with grip.

Bosh

Rubber ridges



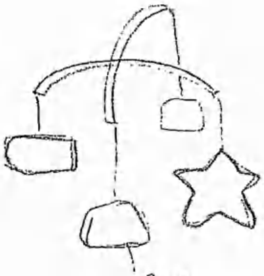
may be better on underside of handle but nice effect.

- more interesting. Would this wear quickly though?

2nd April 2001

- Mother case -

Mobile



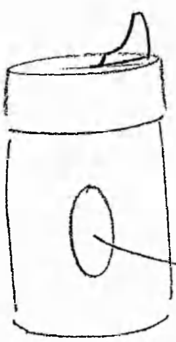
soft - fluffy
- not a very strong grip. quite slippy

- Cloth mobile -

- easier to grip
- if shaped for hand grip, could get a good grip
soft - as cloth and stuffed inside

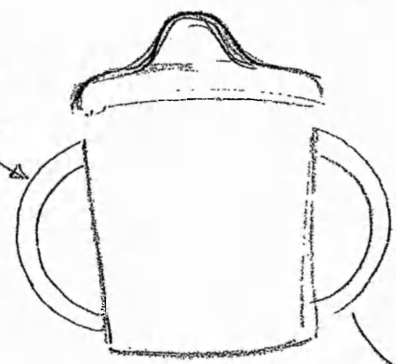
- soft animal mobile
- can get a good grip ~~of them~~ if not too large

No spill cup



hole to grip cup

Toddler cup

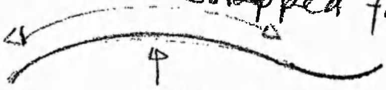


Small handles are easy to grip

even easy to grip with 2 fingers - if small space.
|
more force available, using whole hand.

Weaning spoon

Easy to hold



Shapped for easy hold.

some rubber gripping

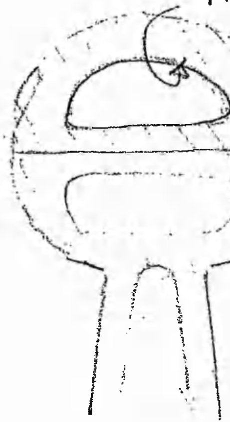
all weaning spoons have this shape.

- Plastic - quite good surface contact - not too slippy.
- Rubber - may get tacky

- Difficult to spin something without using thumb.
  ① + ② are difficult without thumb

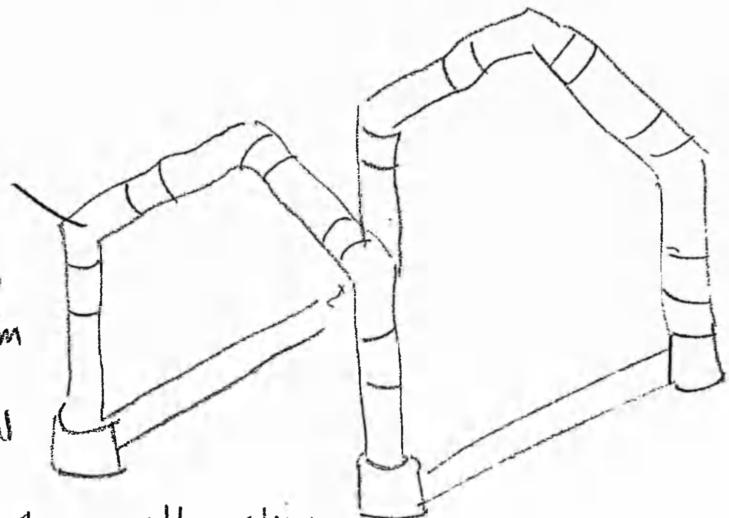
rounded - symmetrical handle. comfortable and grip without thumb

top of push car



- Touch pad · Simple Interface
  - touch → reaction
  - pressure → reaction

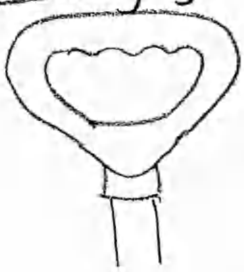
Kick 'n crawl barn



foam + plastic covering - like arm band material

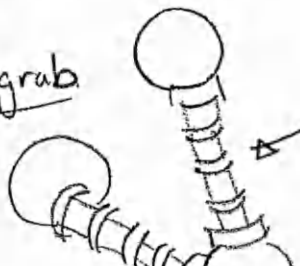
- soft - perhaps alternative covering - also wipe-able

Push ladybug



handle with finger shaping
- nice for gripping

Grip & grab rattle

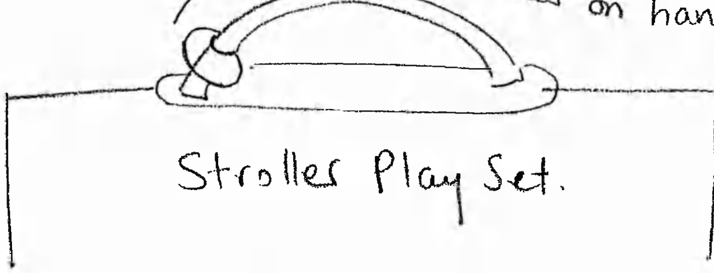


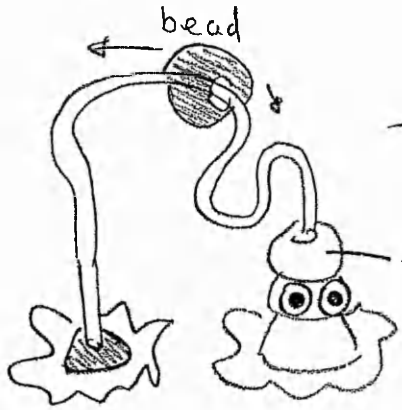
ridges for gripping help.

- Beeny Moose

- nice texture to hold

bead Sliders on handle of pack - nice feature

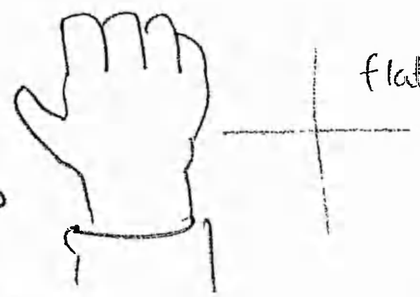




- Soft squishy toys in set too

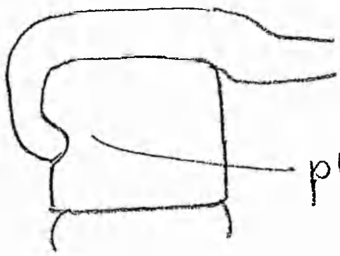
- ☆ difficult to grip

without using thumb



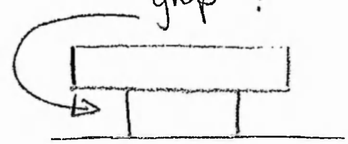
flat Plane

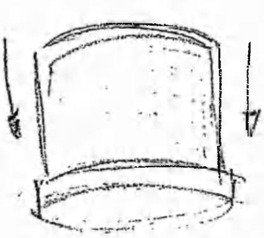
may get sufficient grip like this



place to get a grip

grip ?



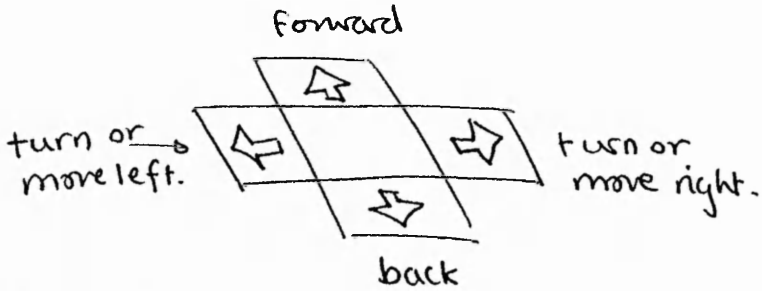


stacking cups

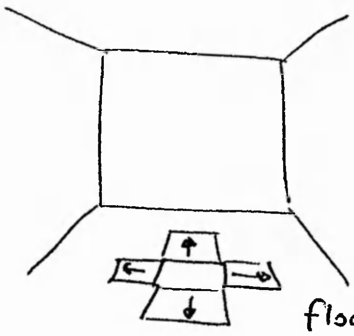
difficult to get firm grip when sides are straight

Ideas from Visit to mothercare - 02/04/01

Touch Pad - Simple interface



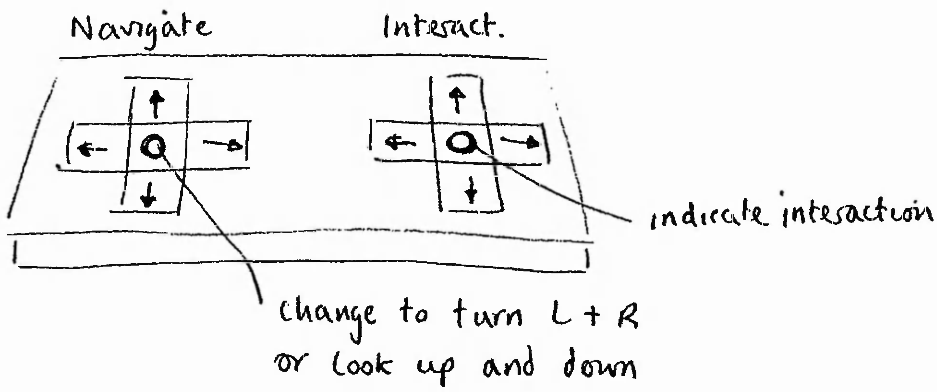
- touch pads
  - would not require much hand control.



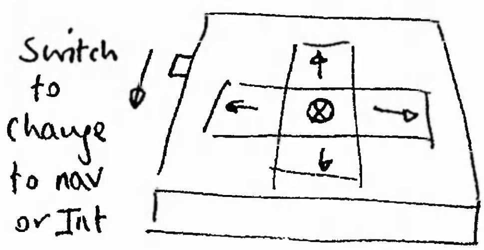
- not so practical if using with computer screen.
- better if using CAVE type environme[nt]

floor mats - choose direction by stepping on mat.

Touch-pads



or All in 1

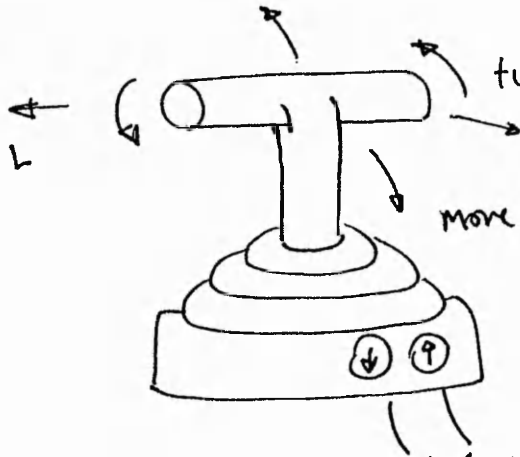


Then

- try out some intefaces with the students
- Go onto next design requirement for a bit

Logical Solutions → Prod funct Analy[sis] → Analogies / proverbs / Clichés

 ← Thesis recording ← prototyping ← Testing with school



- need wrist / arm support - too -

— look up and down —

- Rollerball - able to use - but not so defined/clear movement.
  - bit less concrete - (I think).

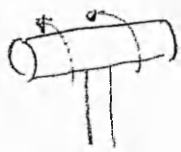
Shampoo + toiletries

- sainsbury's

- not great purchase on top
  - think would cause cramp in hand - even if shaped more to fit palm - or right size

hard to grip without thumb

- not comfortable grip either
  - not as comfy as gripping



Mitchum

harder to grip than VIC due to height of top

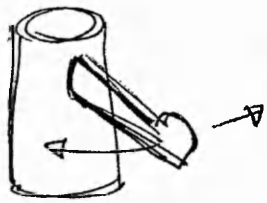
Home base

Shape good for spinning

Side - difficult - not comfortable

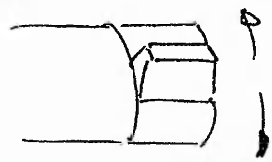
- all in all - not most comfortable design to hold

Shape - gives quite good purchase
fingers curve over nicely - and grip under bottom



- note concept.

Clear indication of turning L + R



- Concept -

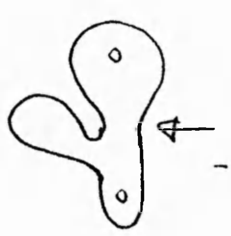
look down up

- not really comfy grip - but secure without using thumb

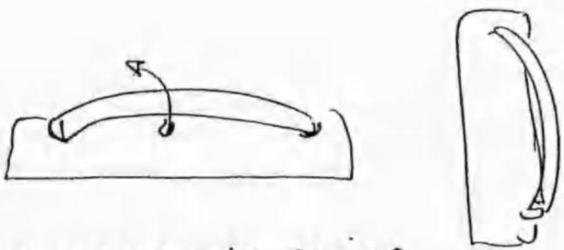
again - f + B fine, rotate fine
but L + R more difficult.

Cabinet handles

good purchase
I like being able to grip like this

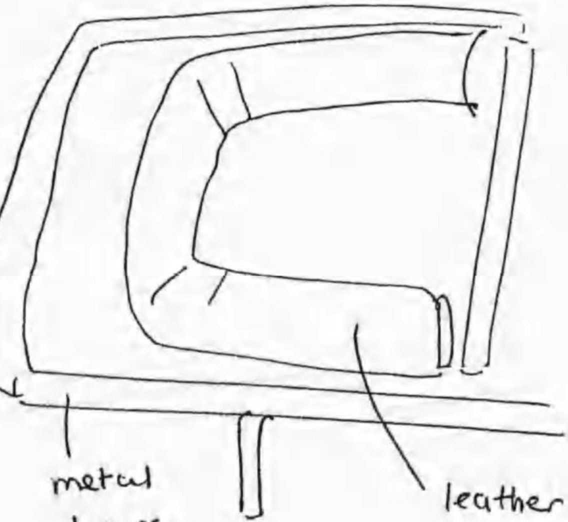


firm purchase
- not comfortable shape though.



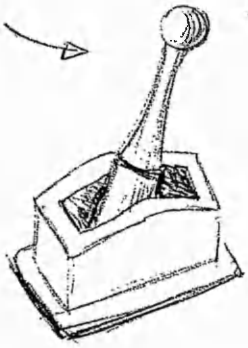
- Some movements easier in horizontal plane - Rotate L + R
- Some moves easier in vertical i.e move L and Right.

Walkers + equipment at Shepherd School



Spacekraft

Roundthorn switch.



- Touch-feely materials & Activity balls

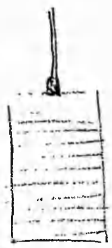
QED

Single switches

large single, brightly coloured switches.

taction Pads

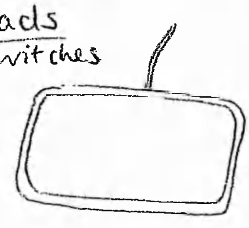
touch sensitive



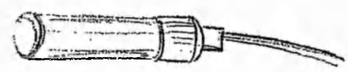
adhere to surface of object act like switch

touch pads switches

bright colours

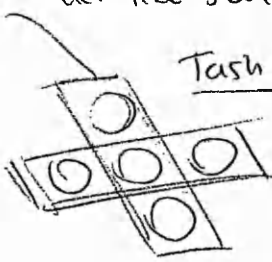


Tash Grasp Switch.



Activated by squeezing 1" diameter rubber hand grip.

Tash Star switch

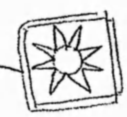


- can be used with Mouse mover. to control cursor

5 way multiple switch.

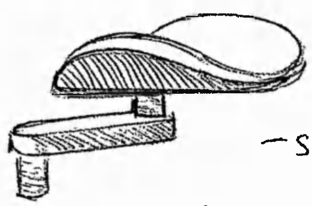
Overlay Pockets

clear adhesive backed pockets



→ symbols onto device.

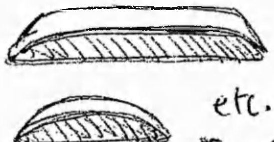
Ergo Rest Mobile Arm Support.



Clamps on-to surface.

- support for forearm when eating typing or working at a table
- reduces fatigue, strain, improves arm mobility + dexterity.
- height adjustable.

- different clamp sizes avail
- 3 sizes of arm support are available.



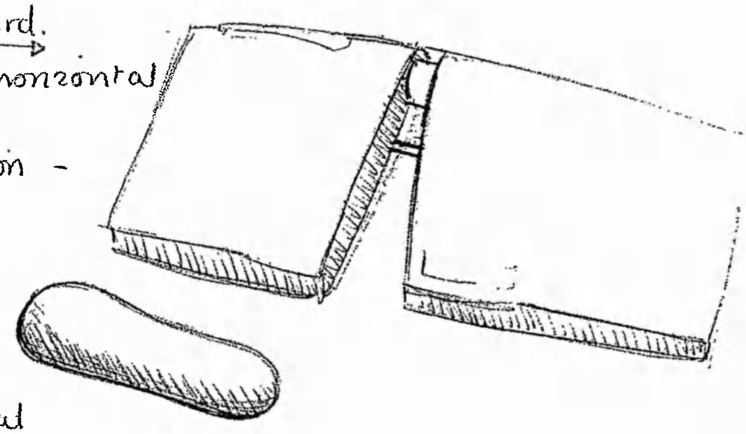
etc.

2 look like this.

Interface and muscle support research

| Keytools |

Goldtouch ergonomic keyboard.



(P4) - adjust for wrist splay - horizontal plane 0°- 30°
- adjusts for wrist pronation - vertical tenting : 0°-30°
- good ergonomic ~~writing~~ /typing position.

- Shaped mouse - replicates natural curve of hand and fingers at rest.
- can be reprogrammed to achieve optimum ergonomic advantage.

Soft - gel-filled wrist-rests + mouse platform. - support when using mouse + keyboards. - finished in Lycra, easy on skin. as are on muscle

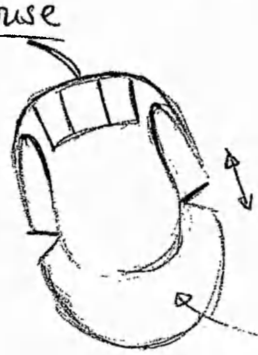
PACE Ergonomic

- allows full adjustment of tilt, twist and angles in all directions.
- adjustable in 3 dimensions (P 9)

Anir Ergonomic Mouse - Avoid RSI

- 2 sizes - medium and large
  medium for most hands, large for larger hand.
- mouse click uses stronger thumb rather than fingers.
- uses upper-arm movement to reduce strain on lower-arm.
- provides hand-support.

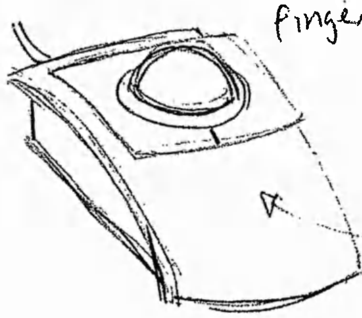
Whale Mouse



- extends by 1.5" for longer hands

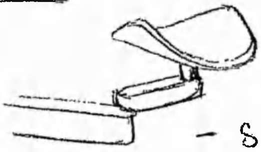
Contoured palm-rest, supports hand encouraging neutral wrist, hand and finger positioning.

PC Trac



low profile case acts as a natural hand-rest, mirroring natural contours of hand.

Arm Support



Clamp here.

- supports forearm. - without hindering free movement

- Intellikeys. Keyboard.

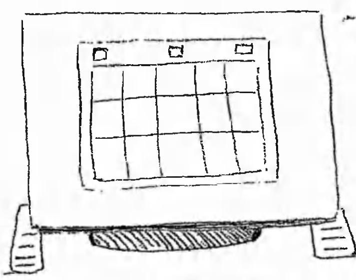
pivots. so you can switch between keyboard and mouse.

RJ Cooper + Assoc.

CAC - Cambridge Adaptive Communication

Cameleon 3

can be adapted to control infrared devices around your home



- speech output communication aid.
- access with switches, touch screen, remote head pointer, mouse or keyboard

MANY OPTIONS FOR ACCESS

- hand held, fitted to a desk stand or wheelchair mounted

- wheelchair mounting solutions

SEMERC - 2001

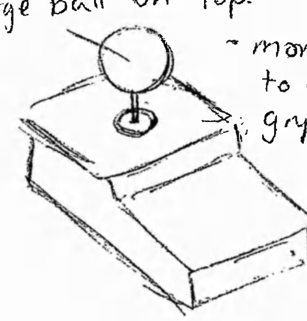
- buttons quite out of way.

nice shapes.

SEMERC Joystick

- is Penny + Giles.

large ball on top.



- more difficult to hold than grip bar.

Mini Mouse

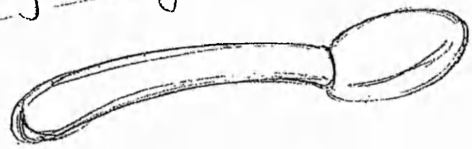
- small for younger children or computer users with small hands
- illuminates when user clicks it.

everyone can see if successful press has been made.

translucent.

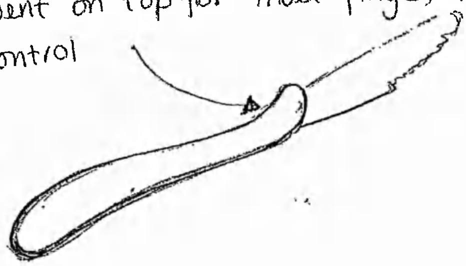
Height adjustable computer trolleys

Caring Cutlery



- contoured plastic handles
- built-up ends.
- for weak grip and restricted wrist or finger movement.

- knife + fork have shaped indent on top for index finger, to help with direction control



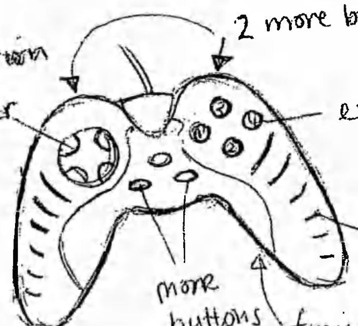
Homecraft Utensils

- easy bending to any angle to accommodate reduced RoM.

comfortable built-up rubber handle

ridges to assist gripping

GRAVIS - ELiminator GamePad Pro



- navigation controller

2 more buttons

- Shaped to fit shape of hand

extra buttons

rubber ridges to assist with gripping

more buttons

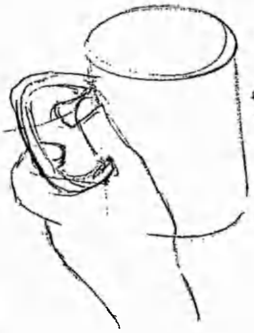
fingers wrap round this part.

Side-view

finger posistion

This side fits into palm well

Thumbs- up - cup.



- for limited strength or co-ordination

[Dycem - Gripmats]

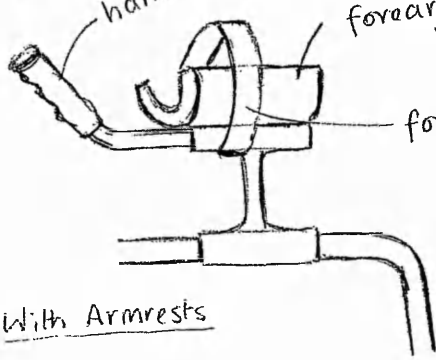
- non-slip material
- grips on both sides to prevent movement on dry slippery surfaces.
- not effective when wet.

[Anchorpads] - prevent objects placed on them from slipping

[Shock absorbing sticks]

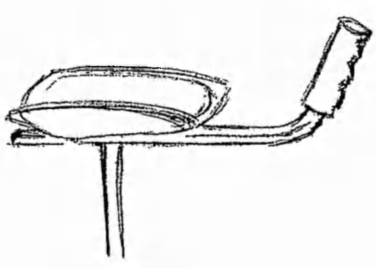
- unique gel hand grip to cushion the hand

Adjustable Trough



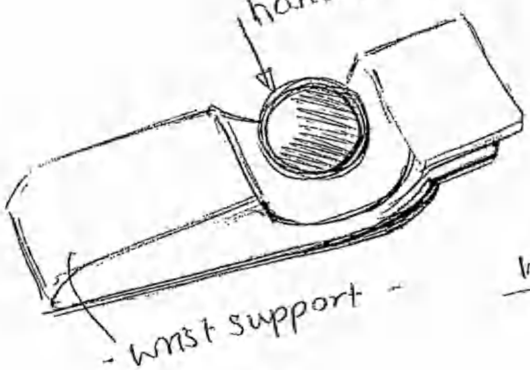
Wheeled Walker With Armrests

- Like special needs Walkers.

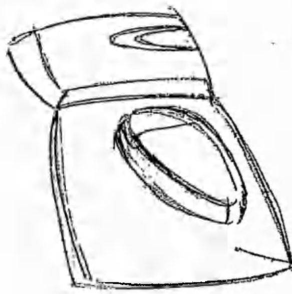


[Wheelchair trays provided]

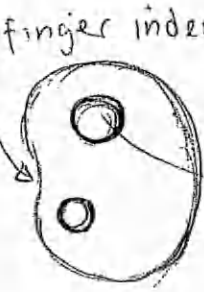
Spaceball 6 DOF
by Spatial Systems.



WingMan force feedback Mouse.

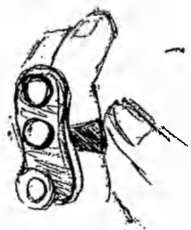


Palm Mouse



- compact + fit in palm.
- grip / hold in the palm.

Ring Mouse.



- another interface idea.

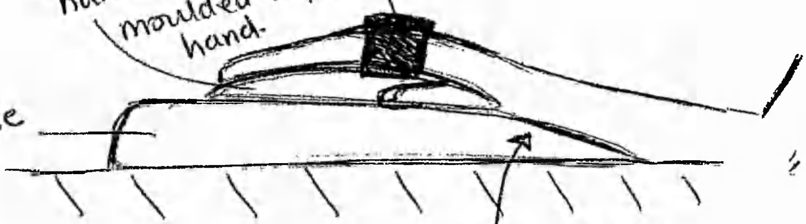
- L or R index finger thumb to activate buttons.
- uses ultrasonic + infrared technology, as your finger moves, the cursor follows.

TrackMan Live

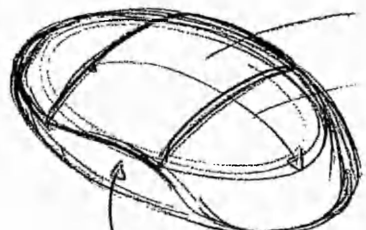
- wireless hand-held pointing device
- trackball for controlling cursor.

Recap on Interface design Research

Materials - many types - soft - rubbery etc. (flexisoft)
can get tacky + sticky + discolour.
finger grips - fingers indents + shaping.
Hand shapping - moulded to fit in the hand
shapes to give a better grip

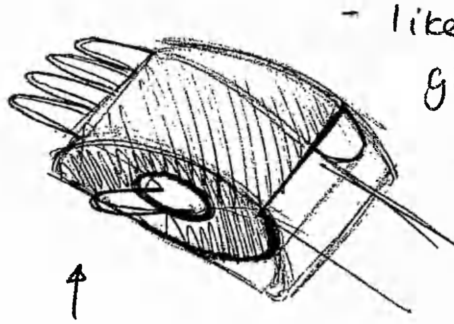


- Shown for right handed use -



Comfort is most important.
+ robustness.

" Put on the device "
- like putting on a glove.



- users may be using one hand to operate both devices.

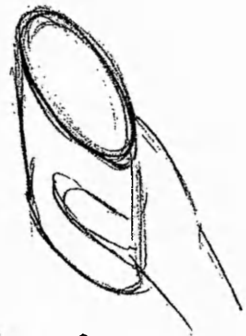
- too fiddly.

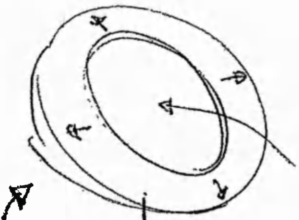
More interfacing without gripping

— with joystick

Movement. - requires more wrist twisting - which could cause more RSI

rather than





→ twist for turn is more difficult with joystick type device than

resting and sliding hand

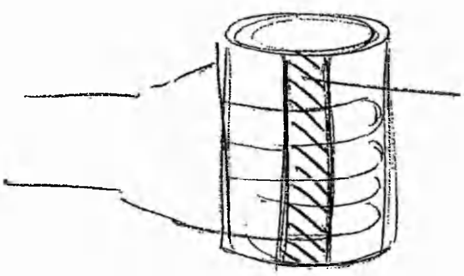
Would allow complete resting of wrist and arm too.

- Joystick position - not so comfortable as

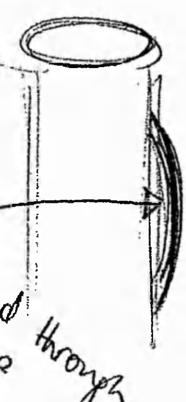
as wrist on edge - not flat.

Need to look at DRP and Neutral wrist position
- get Erg book necessary. -

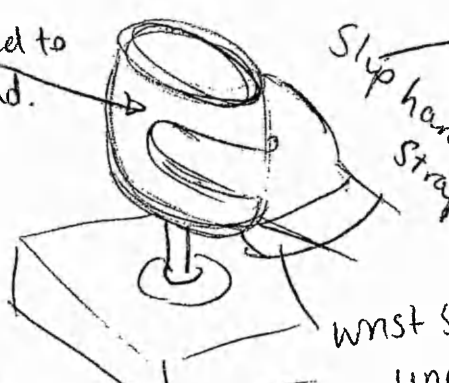
need to assess, which movement is the most comfortable



hand strapped in place



or strap fixed over hand after holding stick for extra stability



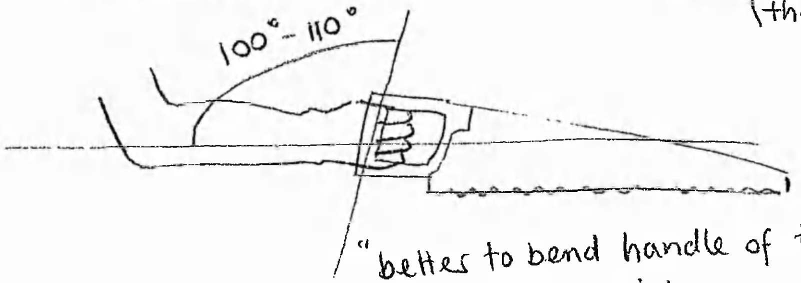
Shapped to fit hand.

Slip hand through strap

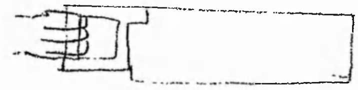
wrist support needed too. under the wrist.

or slidding function.

- Neutral wrist position continued - (Bodyspace : Anthropometry, Ergonomics and the Design of Work. S. Pheasant (1996))



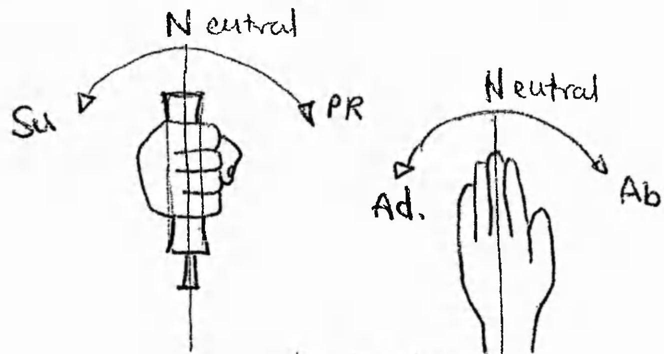
Wrist would not be in neutral position.



"better to bend handle of tool than user's wrist.

- Neutral position. - no bending of the wrist.

Joint ranges

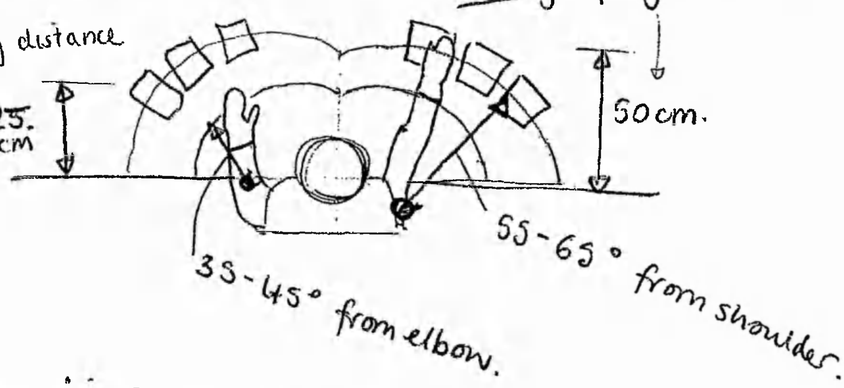


	5th	95th	50th
- Pronation	37	117	77
- Supination.	77	149	113
- Wrist flexion	70	110	90
- Wrist extension	78	120	99
- Wrist abduction (radial)	12	42	27
- Wrist adduction (ulnar deviation)	35	59	47

The normal working area

grasping distance. - Shoulder to hand distance

elbow - working distance to hand.



Human factors in Engineering and design
MS Saunders + EJ McCormick. (1992)

- Ensure not undue deviations from neutral positions
- Configuration of wrist joint permits movements in only 2 planes, each at approx 90° to each other.

Appendix J

- Concept Review (Usability Team Feedback)
- Concept Selection Matrices (and selection criteria)
- Selection of Dimensioned Drawings

Usability team feedback (on concepts)

Table 1. Navigation concepts – usability team feedback

Concept	Feedback
Joystick	Not keen on changing mode feature; progression of device difficulty using the separate handset was liked; **new ideas** - navigation and interaction functions in one device to prevent too much switching between devices; secondary navigation functions controlled by tilting movement
Horizontal grip	Using a strap to secure the hand could restrict the user
Pivot 1	This concept may be quite difficult to engineer; not keen on there being two different hand interface positions
Pivot 2	The user would have to lift their hand/arm off the rest to achieve left/right turn; **decision** – leave out
Pressure options	Using pressure is likely to put strain on the wrist; displacement should be used as this would give the user visual and kinaesthetic feedback; **decision** – leave out
Buttons interface	A concept that would be suitable for user with lower cognitive ability; the user may have to keep looking at the interface to choose the correct button (not transparent)
Communication board	As all the functions are on one board, it may not be easy for the user to choose the correct function; **decision** – leave out
Mojo 2	This concept uses gross motor movement, hence, would be less accurate than a hand controlled device; could be motivational
Standing platform	This device may not be appropriate, as would require quite good stance; could be used for improving stability and could be quite motivational; **decision** – focus on fine motor control device for now, leave out
Touch surface	Would have to move hand when came to end of touch surface
On-screen interface	Would need to be quite close to screen if using touch screen; not very direct navigation, as need to move cursor over icon; **decision** – leave out
Floor pads	Would need to have quite a lot of space in environment; could be quite fun to use; **decision** – focus on fine motor control device for now, leave out
Tracking	A user may become distracted and lose their place in the VE; **decision** – leave out
2-hands control	Not all users can grip well with both hands; would be suitable if it could be used with just one hand; similar to a bicycle, which might be familiar to the users; could be motivational

Table 2. Interaction concepts – usability team feedback

Concept	Feedback
Joystick/screen	It is good that the joystick returns to the centre; the navigation and interaction devices should be quite different; could the interaction device be part of the navigation device?
Trackball	Difficult to add direction guide plates to this device; it could be an advantage that you don't have to grip this device
Touch-monitor	Disadvantages – need to be close to the screen; arm strain in use
External cursor	Using a larger, brighter on screen cursor would achieve the same aim; **decision** – leave out
Data-glove	Your hand could appear on the screen when you put the glove on, so that you don't need the box
Buttons	This interface may be easier to understand for users with lower cognitive ability

Concept selection matrices

Selection criteria – design requirements

Product appearance

1. Modern style

Ergonomic design

2. Ensures neutral operation position
3. Appropriate interface (i.e. grip)
4. Operated with left/right hand/arm
5. Not require fine finger operation
6. Provides muscle support
7. Interface - comfortable form
8. Can be repositioned, without tools
9. Avoids static muscle loading
10. No sharp edges/ raised parts
11. Buttons – appropriate position
12. Stable in use
13. Light/comfortable to carry
14. Operable within visual field

Interface and functional assistance

15. Form indicates interface
16. Visual cues to interface
17. Essential details/components highlighted
18. Form indicates function
19. Visual cues to function
20. Form indicates device orientation

Cognitive factors

21. User action maps to VE function
22. Modifiable operation difficulty
23. No excess functions
24. One user action = one VE function
25. Movements are specific
26. Consistent function for individuals
27. Is transparent
28. Returns to centre position
29. Familiar function (analogy)

Physical factors

30. Adjustable inertia
31. Variable range of movement
32. Provides necessary assistance
33. Smooth operation/action
34. Not detect unintentional actions (i.e. tremor)
35. Avoids cross-lateral movement
36. Robust construction
37. Calibration for balance
38. Detects fast/slow user actions
39. Non-interference (i.e. cabling)

Control functions

40. Navigation/primary – forward/back move; left/right turn
41. Navigation/secondary – left/right move; look up/down
42. Interaction – direct or control cursor
43. Fine movement function

Computer input

44. Compatible with PC
45. Self-contained (minimal parts

Concept selection matrices

Matrix 1. Navigation concept selection – reference concept = joystick

	Joystick-mode	Tilting joystick	Pivot-1	Buttons interface	Trackball	Touch-surface	2-hands control	Combined inter.
1	+1	+1	+1	+1	+1	+1	+1	+1
2	+1	0	0	+1	+1	+1	+1	0
3	+1	+1	+1	+1	+1	+1	+1	+1
4	0	0	0	0	0	0	-1	-1
5	+1	+1	+1	0	+1	+1	+1	+1
6	+1	+1	+1	0	+1	+1	0	+1
7	+1	+1	+1	0	+1	+1	+1	+1
8	0	0	0	0	0	0	0	0
9	0	0	0	-1	-1	0	+1	+1
10	0	0	0	0	0	0	0	0
11	+1	+1	+1	+1	+1	+1	+1	+1
12	+1	+1	+1	+1	+1	+1	+1	+1
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	-1	-1	0	0
16	+1	+1	+1	+1	+1	+1	+1	+1
17	+1	+1	+1	+1	+1	+1	+1	+1
18	0	0	0	+1	0	0	+1	+1
19	+1	+1	+1	+1	+1	0	+1	+1
20	+1	+1	+1	+1	+1	0	+1	+1
21	0	0	+1	0	0	0	+1	+1
22	+1	0	+1	+1	+1	0	+1	+1
23	0	+1	0	0	0	0	+1	+1
24	0	+1	+1	+1	0	0	+1	+1
25	0	0	+1	0	0	0	+1	+1
26	0	0	0	0	0	0	0	0
27	0	+1	0	0	0	0	+1	+1
28	0	0	0	0	-1	-1	0	0

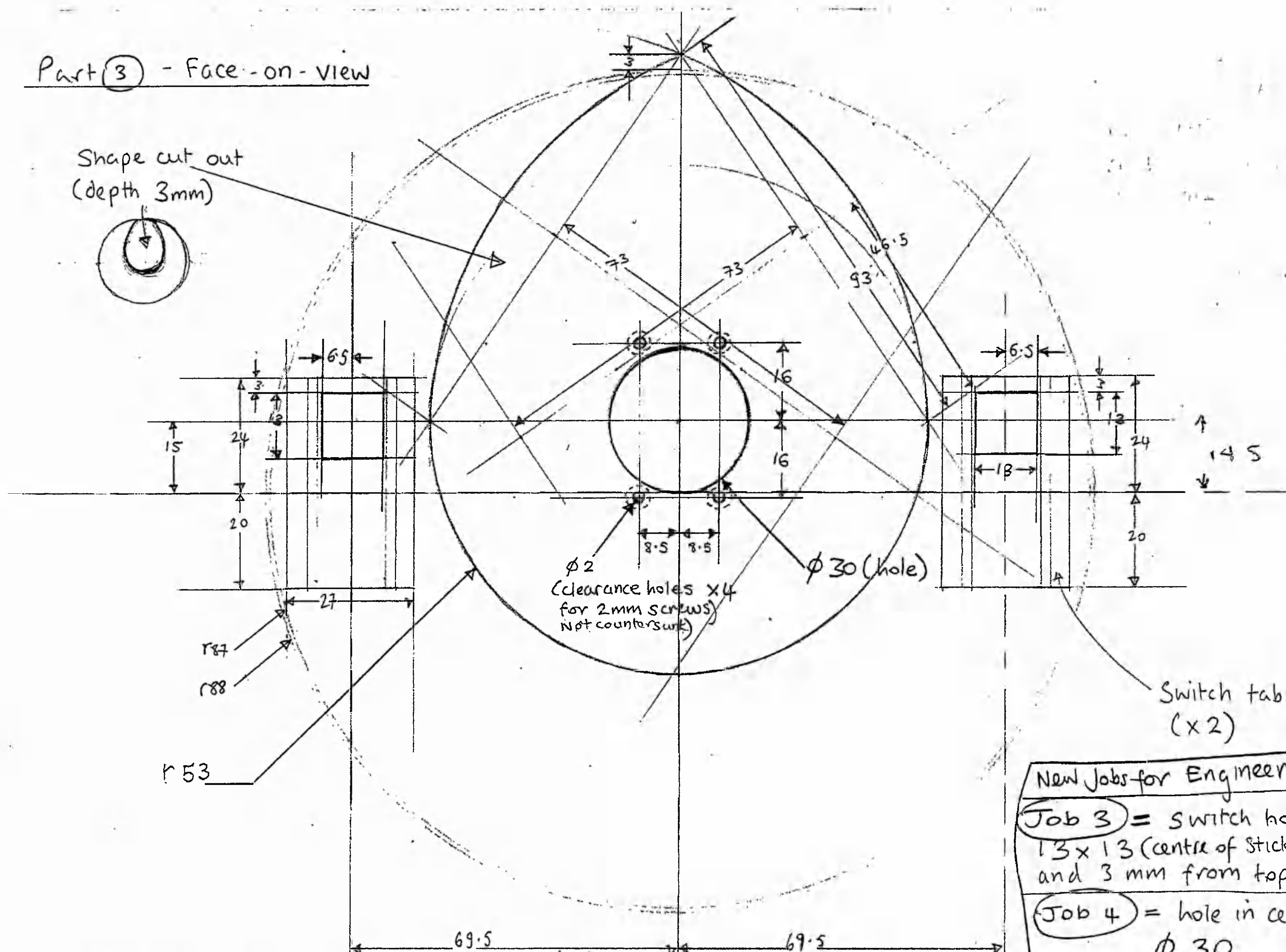
29	-1	-1	-1	0	-1	-1	0	0
30	+1	+1	+1	0	0	0	+1	+1
31	+1	0	+1	0	+1	+1	+1	+1
32	+1	+1	+1	+1	0	0	+1	+1
33	0	0	0	0	0	0	0	0
34	0	-1	0	-1	-1	-1	0	0
35	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0
37	0	0	0	0	-1	-1	0	0
38	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	-1	0	0	0	0	0
42	-	-	-	-	-	-	-	-
43	-	-	-	-	-	-	-	-
44	0	0	0	0	0	0	0	0
45	0	0	-1	-1	0	0	0	0
	Joystick-mode	Tilting joystick	Pivot-1	Buttons interface	Trackball	Touch-surface	2-hands control	Combined inter.
T	15	14	15	10	8	6	21	21

Matrix 1. Interaction concept selection – reference concept = mouse

	Joystick-screen	Horizontal grip	Joystick	Trackball	Touch monitor	Touch-surface	Data glove	Buttons
1	+1	+1	+1	+1	0	+1	0	+1
2	0	0	0	0	-1	0	-1	0
3	+1	0	+1	+1	+1	+1	+1	+1
4	0	0	0	0	0	0	0	0
5	+1	+1	+1	+1	0	+1	+1	+1
6	0	0	0	0	-1	0	-1	-1
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	-1	-1	0	-1	-1
10	0	0	0	0	0	0	0	0
11	+1	+1	+1	+1	+1	+1	+1	+1
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	-1	-1	-1	0	0
16	+1	+1	+1	+1	0	+1	+1	+1
17	+1	+1	+1	+1	0	+1	+1	+1
18	0	0	+1	0	0	0	0	+1
19	+1	+1	+1	+1	0	+1	0	+1
20	+1	+1	+1	+1	+1	+1	0	+1
21	0	0	+1	0	+1	0	-1	-1
22	0	0	+1	0	0	0	0	+1
23	0	0	0	0	0	0	0	0
24	0	0	0	0	+1	0	0	0
25	+1	+1	+1	0	+1	0	0	+1
26	0	0	0	0	0	0	0	0
27	0	0	0	0	+1	0	0	-1
28	+1	+1	+1	0	+1	0	0	+1
29	-1	0	0	-1	+1	-1	-1	0
30	-	-	-	-	-	-	-	-

31	0	0	0	0	-1	0	0	0
32	0	0	+1	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	+1	+1	+1	+1	0	0	+1	0
35	0	0	0	0	-1	0	0	0
36	0	0	0	0	0	0	-1	0
37	-	-	-	-	-	-	-	-
38	0	0	0	0	-1	0	0	0
39	0	0	0	0	0	0	0	0
40	-	-	-	-	-	-	-	-
41	-	-	-	-	-	-	-	-
42	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0
45	0	0	0	0	+1	0	0	0
	Joystick-screen	Horizontal grip	Joystick	Trackball	Touch monitor	Touch-surface	Data glove	Buttons
T	10	10	15	6	3	6	0	8

Part 3 - Face-on-view

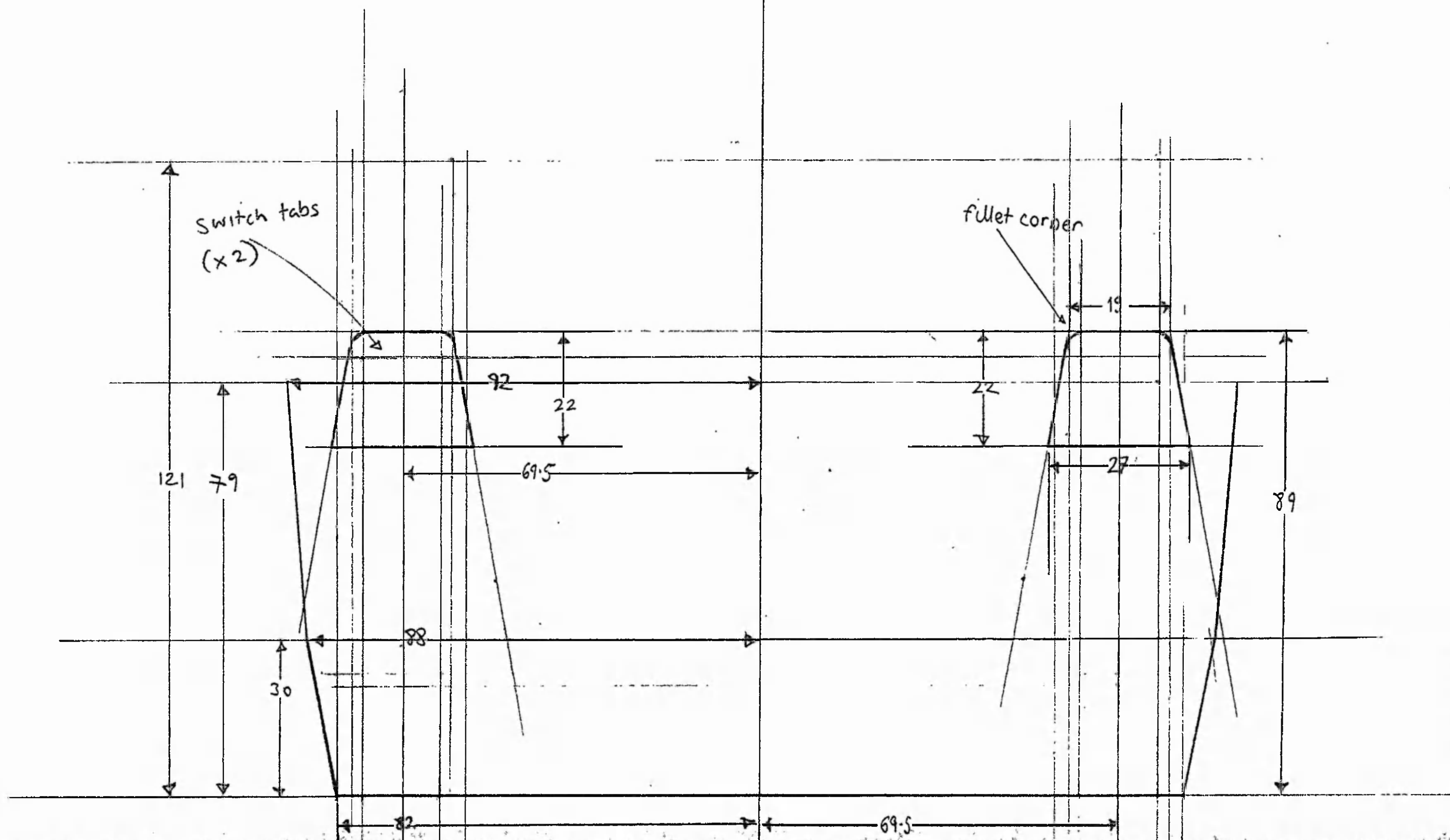


New Jobs for Engineering

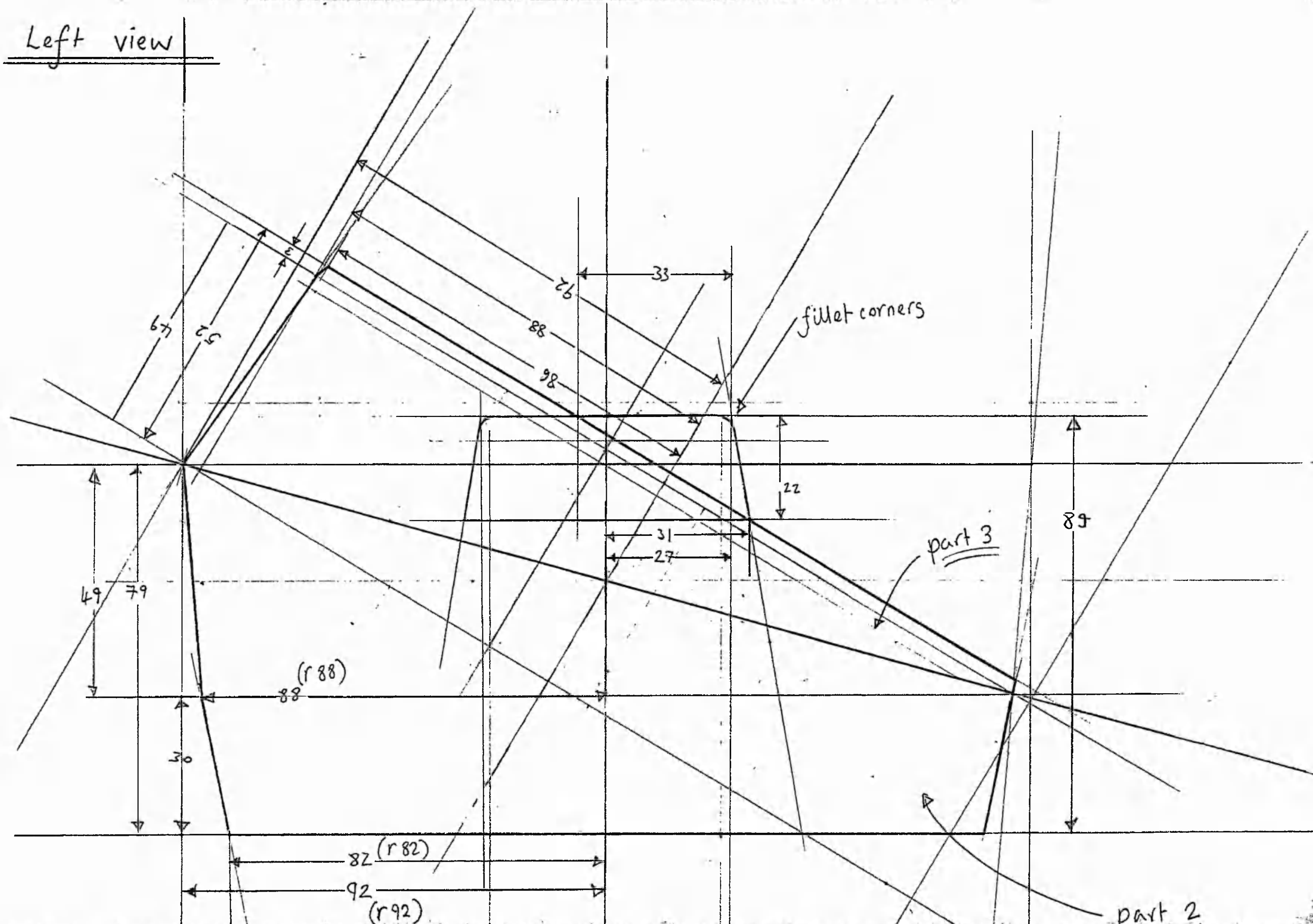
Job 3 = Switch holes
13 x 13 (centre of sticking up
and 3 mm from top edge

Job 4 = hole in centre
ϕ 30

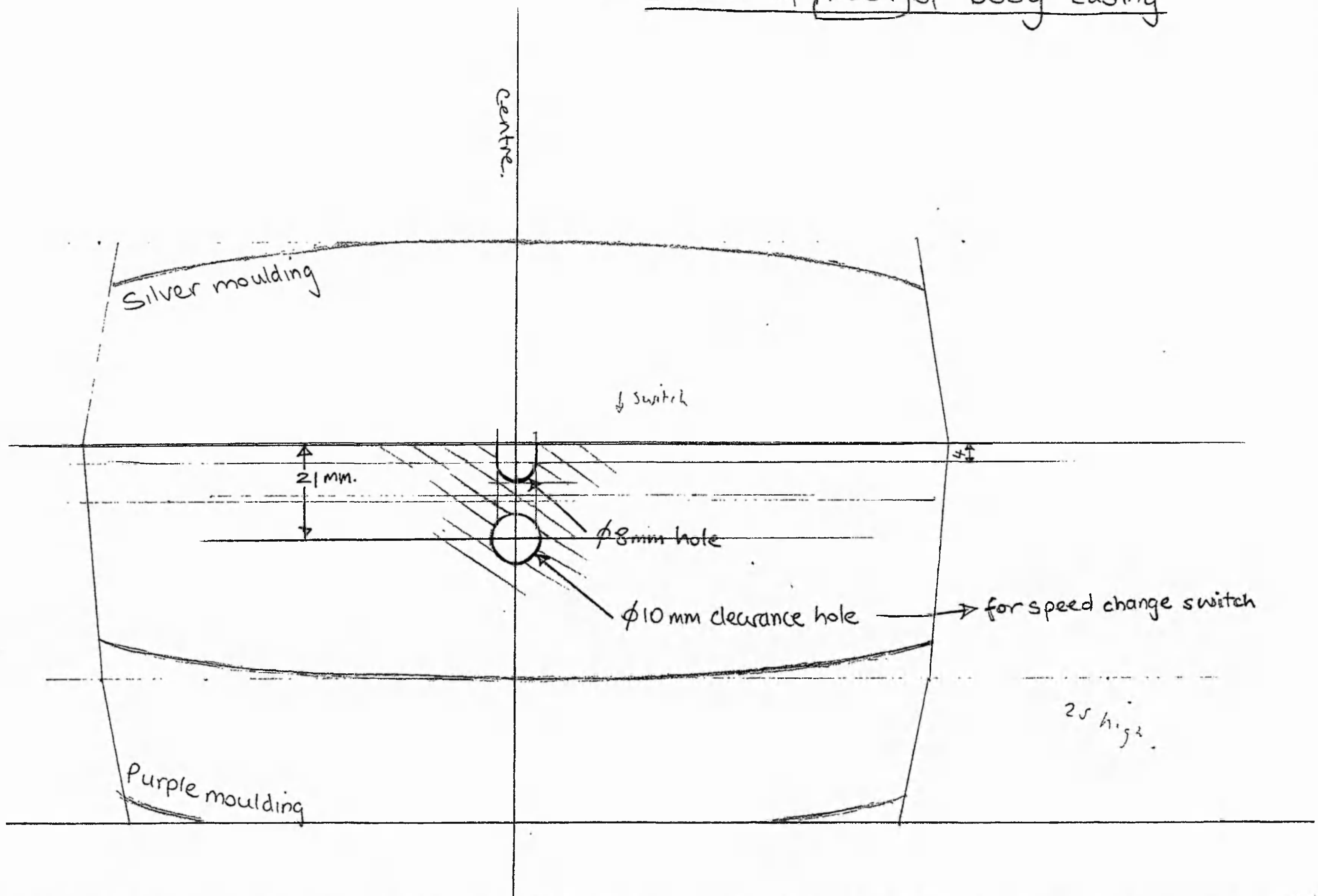
Front View


Switch tabs
(x2)
fillet corner
121
79
30
92
22
69.5
88
82
69.5
22
19
27
89

Left view


fillet corners
part 3
part 2
33
22
31
27
89
92
88
98
49
52
3
49
79
88
(r 88)
30
82
(r 82)
92
(r 92)

- Sketch of back of body casing

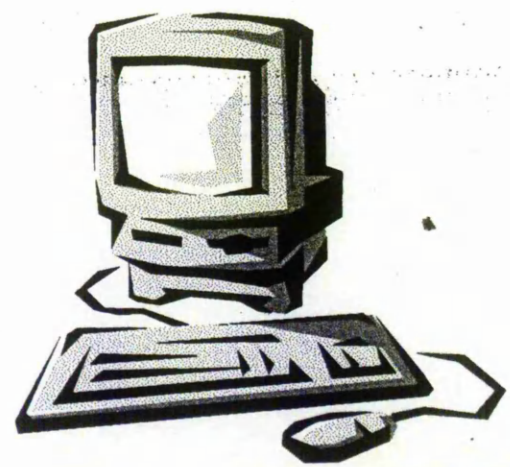


Appendix K

- VRD (Virtual Reality Device) user group presentation – overhead projector slides
- Certificate of Appreciation

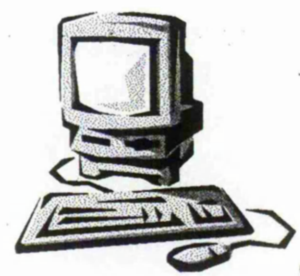
VR-1 Evaluation

By the Shepherd School



User Group

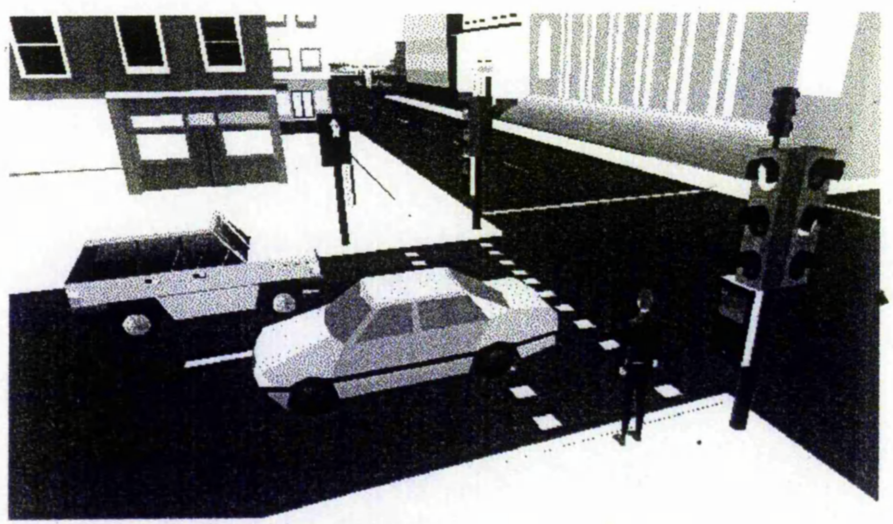
- You are in the VR-1user group
- We would like you to test VR-1 and tell us what you think of it:
  - Easy to use?
  - Looks nice?
  - Enjoy using it?



- We would like you to test VR-1 about 5 times

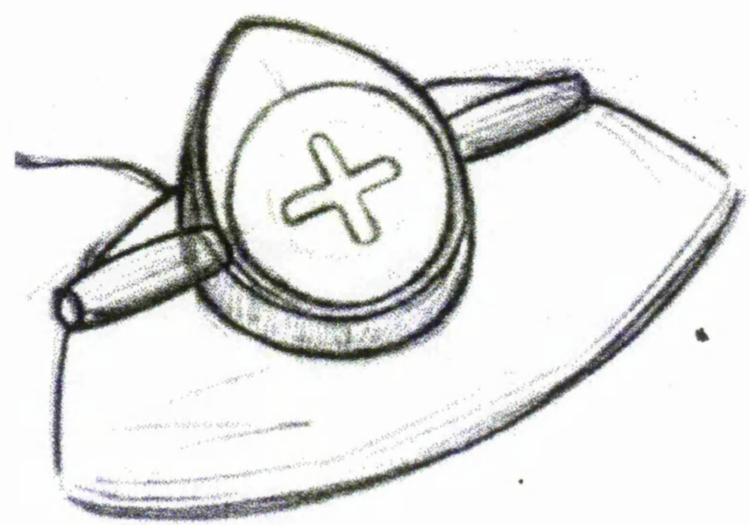
Virtual environment

- Here is a picture from a 3D world



VR-1

- VR-1 is used to do tasks in the 3D worlds on the computer



Thank you  

- Thank you for coming today
- The evaluation will start after the holiday
- We hope that you enjoy the food and music
- We wish you all a happy half term break

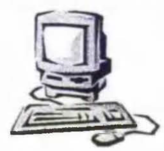
- Best wishes from Tanja and Omi

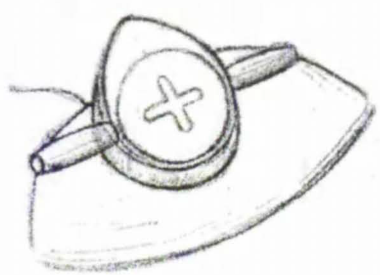
The Nottingham Trent University

CERTIFICATE OF APPRECIATION

This certificate is awarded to

____





in recognition of valuable contributions to

The Virtual Reality Input Device project

19th December 2001
Date

19st December 2001.
Date

Appendix L

- Usability Checklist (completed examples)
- Definitions of observations
- Extended Usability Specification (completed examples)
- Performance Measurement Tables (completed examples)

Usability Checklist

Name	E
System	VR1
Set up	I, 27/11/01; j, i 4/12/01; I, 6/12/01

User actions/movements	
Session 1 Reset to I as pitch interfering; T1 tried to use I to move forward; turned far left using handles; T2: trying to use I again, instead of N; T2: I slowed down (slowest I think) Session 2 T1: just using L/R turn, not forward (so demo of F); playing with I and I buttons; reset to I due to pitch; T1 again: T stood behind him and showed F by putting hands on his; suddenly moved F easily and lined up with cupboard; used I to open cupboard quite easily; I slowed by 2; T5: used N to move to ladder quite easily Session 3 T1: no problems with N; T2: I slowed by 1, quite forceful with I; able to use device, just too forceful DR – require more resistance to movement on I	
Obviousness – initial test	
Able to use without prior instruction? Grabbed I first, quite rough; used up/down, disorientated; using L/R turn	
Obviousness - training	
Instruction required Session1 Demo – fiddled with device during demo, not listening properly; T4: further demo of F given, as stopped using Session 2 T1: demo of forward again; T1 again: guided through F, T's hands on his Session 3 Will need some help to try to be less forceful with movements	
Obviousness – learning time	
Time taken to become competent 3 sessions	
Predictability – user comments / reactions	
Session 1 Groaning as I not doing what he wants it to	
Predictability – can use after training	
Session 1 Used L/R turn more than F/B move; demonstrated can use primary N functions (can get to a position) and I a bit Session 3 Can use primary N moves and can use I (just quite forceful) and need slowed by 1 DR – could do with detail and large I speeds	
Predictability – harshness	
Due to device not operating as user expects Some harshness possibly due to I not being fast enough	
Compatibility – anthropometric difficulties	
i.e. grip, reach, device size	
Compatibility – biomechanical difficulties	
i.e. ROM and strength Difficulty controlling force of his movements, cause overcompensation with I	
Efficiency – task time	
Session 2: about 5 tasks in 13.09 min Session 3: about 7 tasks in 8 min (ok)	

Efficiency – harshness	
Just being harsh Session 1 T2: Rough handling of I; quite rough with device, T has hand ready to prevent break; T4 large and forceful movements of I DR – device needs to be very robust Session 2 T5: T assisted with selecting ladder as started to use more force (frustration) Session 3 Forceful movement of I sometimes	
Effectiveness – unproductive actions - device	
i.e. overcompensation and using wrong function for a task Session 1 Overcompensating with I; trying to use I for N tasks; T5: tried to use I for N Session 3 Overcompensating with I, due to forceful movements; T4: forceful with I again	
Effectiveness – unproductive actions - task	
Due to device Session 2 T2: clicking on anything	
Unproductive actions - task	
Effectiveness – disorientation	
Frequency Session 2 Disorientated self with pitch twice, helped to rectify	
Effectiveness – rectification	
Rectify quickly, lengthy period or help required Session 2 Helped to rectify disorientation twice with pitch	
Effectiveness – support-verbal	
Frequency, specify (related to device) Session 1 Told to use handles to move forward; T3: prompt to move forward (stuck in door) Session 2 T1: went into corner of entrance, prompt to pull back; T4: prompt to click on oil; T5: prompt to use I to select ladder Session 3 Before start, asked him to use gently	
Effectiveness – support-physical	
Frequency, specify Session 1 T2: slight help to align with cupboard; helped to select some clothes; T4: went too far past oil, helped to get back near oil (understanding of task problem I think) Session 2 T1: physical help to get into building (guiding F); T2: assisted to select clothes (not concentrating); T5: ladder, T assist to select as showing frustration; T6: asked to leave factory, went over danger lines, chased cart Session 3 T4: T thought not going to stop helped him to stop by oil, T helped to select oil by holding I too, as his movements too large, causing overcompensation	

Effectiveness – task completion	
Session 1 T1: managed eventually; T2: physical help to align and select some clothes; T3: not directly in, stopped in door twice, managed eventually; T4: help to get by oil, used I not quickly though Session 2 T1: into side of entrance, verbal help, twice disorientate with pitch, reset to I; T1: physical help into building; T2: aligned himself with cupboard, assisted to select clothes; T3: managed OK; T4: used I ok (13.09 min) Session 3 T1: N straight in and lined up with cupboard; T2: clicked to open, but on reset so back outside; T1: back in again, no problems; T2: managed, but not accurate selecting clothes; T3: fine; T4: done, but required help to control I to select oil; T5: N to ladder well, managed OK; appeared to be loosing interest so told could have a look around factory; went onto danger lines and followed outside, hit by cart (8 mins)	
Satisfaction – user observation	
Session 2 When I slowed down, showed a bit bored (facial expression and head rested on hand) Session 3 Liked hearing sound of man, clicked him 4 times in a row; appeared happier when told could wander, became more lively and active	
Satisfaction – user comments / reactions	
Session 2 T2: made grunting noises, as not finding it easy to select the clothes; T6: found it funny to chase the cart	
Controllability – responsiveness	
Feedback consistent and accurate	
Controllability – non-interference	
Does not interfere with own use Session 2 Pitch causing interference, reset to i	
Controllability – grip surface	
Prevents unintended slipping during use	
Controllability – device access	
Can be positioned, grasped and manipulated quickly and easily	
Controllability – control access	
Can be located quickly and easily	
Biomechanical load – posture	
Operated without undue deviation from neutral posture	
Biomechanical load - effort	
Operated without excessive effort Effort to select some VE objects	
Engagement – interest	
Level of distraction displayed Session 1 Looked at mats and played with themduring demo Session 2 Playing with I and I buttons; T2: watching his movements, rather than screen, not paying good attention; distracted by the cart, chasing it Session 3 T5: clicked on man 4 times, to hear him talk; appeared to be loosing interest in VE now	
User training	
After training, can avoid excessive effort and obtain improved performance	

Further comments	
Session 1 Tried clicking to get through factory doors; asked what he thought of device, said 'OK' Session 2 After session, asked what he thought of device, said 'good); I slowed by 1 – not enough control, I slowed by 2 – too slow for large movement of cursor DR – require a detail and normal I speed setting Session 3 T2: clicked to open, but on reset so back outside DR – not able to reset world by accident	

Good N grip; grip on I ok
Control access fine
Harshness with I, lessened with use
Comfortable
Need work surface a bit lower
Slight effort with I
Slight wrist deviation with L/R turn
Content/happy
Good size; grasp fine; reach fine

Usability Checklist

Name	E
System	Joystick and mouse (JM)
Set up	Axys J (factory, cafe), 18/02/00; 17/12/01

User actions/movements	
Eval 1 Can press mouse button Session 1 T1: went in big circle, found doors; mouse difficult for him	
Obviousness – initial test	
Able to use without prior instruction? Session 1: first pressed button and used pitch	
Obviousness - training	
Instruction required Eval 1: demo of devices and tasks Session 1 Demo of using mouse	
Obviousness – learning time	
Time taken to become competent Eval 1: used J and M with factory and café Eval 2: may just be second go with both devices	
Predictability – user comments / reactions	
Predictability – can use after training	
Eval 1: devices not obvious to him, how to use (understands M for I and J for N) Session 2: Mouse difficult for him; can move with J, but needs help with some navigation tasks	
Predictability – harshness	
Due to device not operating as user expects	
Compatibility – anthropometric difficulties	
i.e. grip, reach, device size Eval 1: not comfortable grip, looks quite awkward; just able to reach, desk could be lower to help him; grip not very good on Axys J	
Compatibility – biomechanical difficulties	
i.e. ROM and strength Eval 1: sufficient strength, but not channelling it in right way	
Efficiency – task time	
Efficiency – harshness	
Just being harsh Eval 1 Quite firm with both J and M, but not distructive	
Effectiveness – unproductive actions - device	
i.e. overcompensation and using wrong function for a task VA: before started, repeatedly pressing J button Eval. 1 Pressed J button; pressing right M button; pressing M button repeatedly; T4: not clear to him to use left M button Session 1 Twists mouse round, not straight on; random pressing of joystick button	
Effectiveness – unproductive actions - task	

Due to device Eval 1 Some random movement of both J and M; T1: random movement with J; T4: random movement of M; T5: pressed J button and went upside down (playing) Session 2 Going upside down, using joystick button	
Unproductive actions - task	
Effectiveness – disorientation	
Frequency Session 1 T1: disorientated, upside down (found funny, so may have been playing)	
Effectiveness – rectification	
Rectify quickly, lengthy period or help required T1: rectified by T	
Effectiveness – support-verbal	
Frequency, specify (related to device) Eval. 1 Frequent prompting for interaction and navigation Session 1 Before T1: T told user not to press joystick button, but continued to press; T2: reminded not to use joystick button (found it funny, laughing)	
Effectiveness – support-physical	
Frequency, specify Eval 1: physical guidance of J and movement of cursor into position; T1: physical assistance into building; physical assistance to cupboard, assistance to position cursor; T3: assist to enter factory, T hand on his; T4: assist to oil, and to position cursor Session 1 T2: T lined up with cupboard, T assist in selecting clothes; T4: assisted to look down and line up with oil	
Effectiveness – task completion	
Eval 1 T1: in with physical assistance, after random movement, took some time; T2: assistance to cupboard and select clothes; T3: assisted, moved forward himself; T4: assisted both N and I; T5: not move towards, distracted; went onto virtual café Session 1 T1: got in after disorientation and playing; T2: opened cupboard, assisted in clothes; T3: got in; T4: looked up accidentally, T lined up, clicked on oil after playing a bit (9.30min); had to leave to go to play practice	
Satisfaction – user observation	
Eval 1: lots of excitement shown; likes to hear the noises	

Satisfaction – user comments / reactions	
Eval 1: expressed that he wanted to have another go; shows annoyance when T demonstrates (inpatient); happy and smiley generally through evaluation; enjoyed seeing oil being cleared up Session 1 T2: found noises funny (laughing)	
Controllability – responsiveness	
Feedback consistent and accurate	
Controllability – non-interference	
Does not interfere with own use Session 1 T2: pulled back with Joystick and picked whole of J up; joystick buttons distracting and cause disorientation	
Controllability – grip surface	
Prevents unintended slipping during use	
Controllability – device access	
Can be positioned, grasped and manipulated quickly and easily	
Controllability – control access	

Can be located quickly and easily VA: fingers covering M buttons, difficult to locate correct button	
Biomechanical load – posture	
Operated without undue deviation from neutral posture Session 1 Mouse twist cause deviation	
Biomechanical load - effort	
Operated without excessive effort	
Engagement – interest	
Level of distraction displayed Eval 1 Not so interested in doing the required tasks; fidgets with devices; looked at screen a lot; looking at devices to find them; distracted a little by other user (next to be tested) in the room Session 1 T1: moving forward and back, playing; in funny mood, playing a lot	
User training	
After training, can avoid excessive effort and obtain improved performance	
Further comments	
VA – desk too high for him; more gross motor difficulty Eval 1: moves about on his seat; not used VEs before; not used either J or M before DR – comfortable workstation	

Grip: two hands on joystick; able to grip both, but buttons in way
Interfering: pressing J button, even when told not to; mouse lifted up; lift base of J up
Random movement of joystick; aligning difficult
Work surface could be lower
Mouse button location – not easy; actuation fine
Random with mouse
Wrist deviation when twists mouse to left
Not easy to manipulated either device, J or M
M use looks uncomfortable – twisting to left
Happy; effort with both devices

Usability Checklist

Name	Q
System	VR1
Set up	03/12/01, pitch on; 6/12/01, i; 10/12/01, i; supermarket then factory, 11/12/01; super-j, no guide,18/12/01

User actions/movements	
Session 1 T1: F move not easy for him; T5: used pitch to help position the cursor (showing knowledge of pitch), did same for T6; tries to do tasks very quickly, so will try all functions to achieve what he wants to do Session 2 T1: confidently used device; not particularly good control of N yet, but good knowledge of how it works; T2: large movements for turn L/R, causing turning in circles; I slowed by 1; less control with I due to shaky hand movements; T9: using I, N and I button all at same time, rushing to finish the task Session 3 T8: kept falling off stairs on way up, not completely on the stairs; I use is not very controlled, impatient manor, rushing Session 4 T2: bumped into VE lady, looked round to check she was ok Session 5 T1: stuck in trolley park, should have backed out for him; T4: does tasks very quickly; N easily, including pitch; engrossed in VE, device just aid to access VE; T7: great manoeuvring to checkout, and good with I, have to double click items, which is not really easy to do DR – a way of achieving double click more easily, without adding any distraction or confusion	
Obviousness – initial test	
Able to use without prior instruction? Using I, and knew it was controlling cursor; think was looking up/down with pitch; think using L/R turn ok	
Obviousness - training	
Instruction required Session 1 Demo given: user stayed where he was and T put hands on his to guide him through functions (check) Session 2 T2: demo of side-step – not use though Session 3 T9: shown side-step – used once Session 4 Demo side-step – he tried, but not easy, as not returning to centre first; explanation of up/down, using it but in rushing manner	
Obviousness – learning time	
Time taken to become competent	
Predictability – user comments / reactions	
Predictability – can use after training	
Session 1 Rushing with device; managed to use pitch a few times; some use of I (some overshooting) and N (F not easy, large moves with L/R turn) Session 2 Can use N quite well; I also quite good, but also using N to position cursor and using clicking on move method sometimes Session 3 Can use N well; can use I, but control lessened by his rushing; used side-step once Session 4 Primary N well; I good, but uses N too for cursor positioning; can use pitch; used side-step, but not easy for him Session 5 Good use of pitch; good use of primary N; good with I	

Predictability – harshness	
Due to device not operating as user expects	
Compatibility – anthropometric difficulties	
i.e. grip, reach, device size	
Compatibility – biomechanical difficulties	
i.e. ROM and strength	
Efficiency – task time	
Session 1: 8 tasks in 15 min (quite slow – ok) Session 2: 10 tasks in 14.48 min (ok) Session 3: 10 tasks in 10 min (quite fast) Session 4: 10 tasks in 11 min (quite fast) Session 5: 7 tasks in 12.53 (ok)	
Efficiency – harshness	
Just being harsh Session 5 T5: a bit forceful with F move, very eager, rushing	
Effectiveness – unproductive actions - device	
i.e. overcompensation and using wrong function for a task Session 1 Initial test: tried to use plastic on top of I as button; T1: used two hands to push body F, at base of body (not using handles); tried to use I to move F (used to joystick); T2: using N as well as I to position cursor, overcompensating with I for clothes; T5 and 6: using pitch to position cursor too; T8: tried to use pitch and I for forward Session 2 T9: used N to position cursor, as well as I (swapping from N to I, rushing) Session 3 T2: used N to position cursor over cupboard; same combination of N and I to select clothes Session 4 T2 factory: used N to position cursor, as well as I	
Effectiveness – unproductive actions - task	
Due to device Session 2 T2: large turn movements causing going round in circles; T10: bit stuck at top of stairs, managed to get down Session 4 T2: went slightly to left of doors	
Unproductive actions - task	
Effectiveness – disorientation	
Frequency	
Effectiveness – rectification	
Rectify quickly, lengthy period or help required	
Effectiveness – support-verbal	
Frequency, specify (related to device) Session1 T8: verbal guidance out of factory Session 3 T8: verbal prompt to find stairs; T9: slight verbal help Session 4 T2 factory: prompted to just use I to position cursor	
Effectiveness – support-physical	
Frequency, specify Session 1 T2: help selecting some clothes, could probably achieve by self, but might get a bit anxious; T4: T helped to click	

Effectiveness – task completion	
Session 1 T1: managed to get in, N not straight forward yet; T2: in front of cupboard ok, physical help with some clothes; T3: got in after stopping in doorway; T4: ok, T helped to click; T5: F well, clicked on ladder fine, used pitch to help position cursor; T6: managed, using pitch too; T7: fine; T8: forward still not with ease (15 min) Session 2 T1: straight into building; T2: difficult to line up to cupboard, selected by self, clicking on move method; T3: in ok; T4: lined up with oil, I more difficult as rushing task; T5: fine; T6: trolley task completed; T7: completed ok (10 min); T8: upstairs easily; T9: complete container task relatively easily; T10: down and out easy, after first a bit stuck at top of stairs (14.48 min) Session 3 T1: fine with N; T2: used N to position cursor, selected by himself, rushing a bit; T3: fine; T4:fine; T5 and 6: fine; T7: N well using L/R turn and F, completed fine; T8: up eventually; T9: ok; T10: N really well out of factory (10 min) Session 4 T1: straight into supermarket; T2: had a wonder down isle and back up another isle; T3: another wander; T1 factory: in quite easily; T2: managed task, using N for positioning cursor as well as I; T3: managed 2nd attempt; T4: fine, clicking on move; T5: fine, clicking on move and rushing; T6: exited factory fine; asked to try up/down, he could do; asked to try side-step, could do, but needs more practice (not returning to centre is making this more difficult) (11 min) Session 5 T1: stuck in door but managed to get in; T2: N, I and pitch easily; T3: selected oranges after returning a pineapple; T4: selected milk easily; T5: selected biscuits; T6: selected ice-cream, rapid mouse clicking; T7: great manoeuvring to checkout, and good with I (12.53)	
Satisfaction – user observation	
Session 2 T9: determined to finish this task	
Satisfaction – user comments / reactions	
Session 2 Wanted to have another go after this session on another world; T said 'not at the moment', he said 'tomorrow'; hence eager to use VE system Session 4 Came straight in after lunch and forgot to go to registration (shows he is keen); again showed keen as wanted to continue when T asked him to finish	
Controllability – responsiveness	
Feedback consistent and accurate	
Controllability – non-interference	
Does not interfere with own use Session 1 T1: pitch causing some interference, but not taking pitch off; T7: pitch causing slight interference, but coping well Session 3 T5: accidentally knocked N when using I DR – not able to accidentally move N when using I Session 5 T5: pushing forward with slight force, T hold down base occasionally (rushing, determined) DR – may need to be possible to secure base of device to work surface) T7: pitch down by accident at checkout	
Controllability – grip surface	
Prevents unintended slipping during use	
Controllability – device access	
Can be positioned, grasped and manipulated quickly and easily	
Controllability – control access	
Can be located quickly and easily	

Biomechanical load – posture	
Operated without undue deviation from neutral posture	
Biomechanical load - effort	
Operated without excessive effort Session 2 T4: bit of effort using I, think just impatient and wants to do task quickly	
Engagement – interest	
Level of distraction displayed Session 2 T6: user asked 'are you here all day'	
User training	
After training, can avoid excessive effort and obtain improved performance	
Further comments	
Session 1 DR - hand moves quite shaky, so device needs to be more resistive to movement to help control Session 4 T6: asked to leave factory, he said he hadn't done other tasks yet, T said it was ok because he was very good at them already Session 4 Another lady watching this evaluation, this is why this user is having a fifth go with VR1; T3: user chose to return a pineapple as not able to select oranges, showing good intuition; I staying stuck in bottom position (due to wear on prototype)	

Initial test:
Held I, pressed I buttons; twisting handles, pitch; guide plate might be in way; seems to understand pitch (some controls); legs shaking a bit in session 1
Demo:
Explain F and L/R turn; demo with T hands on his, F, B, turn and side-step; explained I, tried to use plastic on top of I to click; managed to use I with only verbal explanation, not full demo

Grip ok with handles; grip I ok; not grasp all way round I, more of a finger grasp
I not great control, need more resistance; buttons I fine
Full movement with I; not much effort I; not effort N
Bit rough with I; not always fully grip N (could be taught to though)
Holding top of I – not proper grip; rushing tasks
Slight wrist deviation when turn L/R
Comfortable; shaky hands; happy; eager

Usability Checklist

Name	Q
System	Joystick and mouse (JM)
Set up	29/11/01

User actions/movements	
Eval 2 T1: couldn't move F as button pressed on joystick; still able to use even though J button interfered a bit; doesn't seem to understand joystick button use; can grip M button ok; manages to position cursor quite quickly; T5: not comfortable use of J, but coping with navigation	
Obviousness – initial test	
Able to use without prior instruction? Not require demo; used before	

Obviousness - training	
Instruction required Eval 2 Short explanation as buttons interfering with use (joystick)	
Obviousness – learning time	
Time taken to become competent	
Predictability – user comments / reactions	
Predictability – can use after training	
Eval 2 Can navigate with J, but doesn't make it look ease, doesn't look comfortable; can use M, bit shaky moves, not comfortable grip	
Predictability – harshness	
Due to device not operating as user expects	
Compatibility – anthropometric difficulties	
i.e. grip, reach, device size Eval 2: grip causing joystick button press; T2: not a comfortable grip on the mouse	
Compatibility – biomechanical difficulties	
i.e. ROM and strength Eval 2 T2: movements with mouse a bit shaky	
Efficiency – task time	
Eval 2: 11 tasks in 9.30 min (quite fast)	
Efficiency – harshness	
Just being harsh	
Effectiveness – unproductive actions - device	
i.e. overcompensation and using wrong function for a task Eval 2 T3: pressing top J button, can't move F; T10: containers, clicking mouse repeatedly on anything	
Effectiveness – unproductive actions - task	
Due to device	
Unproductive actions - task	
Effectiveness – disorientation	
Frequency	
Effectiveness – rectification	
Rectify quickly, lengthy period or help required	
Effectiveness – support-verbal	

Frequency, specify (related to device) Eval 2 T3: told not to press the J button	
Effectiveness – support-physical	
Frequency, specify	
Effectiveness – task completion	
Eval 2 T1: in quickly, facing down (due to button press); T2: used M ok to select clothes; T3: in after pressing J button; T4: fine; T5: fire alarm clicked by accident, not comfortable use of J; T6: trolley, fine; T7: ladder fine; T8: 1st aid, fine; T9: more difficult to N up stairs with J; T10: completed by himself, repeated M clicking; T11: navigated out fine (9.30)	
Satisfaction – user observation	
Eval 2: not relaxed; doesn't look comfortable using J; not comfortable grip on mouse	

Satisfaction – user comments / reactions	
Eval 2 Appeared quite anxious, shaking legs	
Controllability – responsiveness	
Feedback consistent and accurate	
Controllability – non-interference	
Does not interfere with own use Eval 2 T1: buttons interfering with use (joystick); grip causing joystick button press; T3: top J button interfering again, so can't move F	
Controllability – grip surface	
Prevents unintended slipping during use	
Controllability – device access	
Can be positioned, grasped and manipulated quickly and easily Eval 2 Changing grip quite a lot; holding on top; holding at bottom; holding with 2 hands; T2: not a comfortable grip on the mouse	
Controllability – control access	
Can be located quickly and easily	
Biomechanical load – posture	
Operated without undue deviation from neutral posture	
Biomechanical load - effort	
Operated without excessive effort	
Engagement – interest	
Level of distraction displayed Eval 2: very focused on task	
User training	
After training, can avoid excessive effort and obtain improved performance	
Further comments	

Swapping hands to use with J; holding top of J; keep changing J grip
J buttons interfere; not grip J properly; explanation of J buttons given
Not look comfortable grip on M; actuating button on M ok; button access fine
Legs shaking; looking down accidentally
Can move M ok; content; press M button a lot, not always just when over desired object
Big moves of J; holding base of J with other hand; slight wrist deviation F J move
Not really controlled with J

Definitions of observations for:

- Extended Usability Specification
- Performance Measurement table

Observation	Definition
Can use	Able to use all functions of the input device system
Can use well	Able to use all functions of the input device system with apparent ease
Use some functions	Able to use more than one function, but not all of the functions of the input device system
Uncomfortable	Use of the input device system observed to be uncomfortable for the user, e.g. user observed to reach beyond his/her natural range to use the system
Very comfortable	User appeared very relaxed when using the input device system

Extended Usability Specification – User E: VR1 system (performance in bold)

Metric	Worst case	Lowest acceptable	Planned case	Best case	Now
Initial test	Can't use at all	**Use one function**	Use some functions	Can use	\
Training	Lots of further instruction	**Some further instruction**	Demo	No instruction	Demo
Learning time	Infinite	4 sessions	**3 sessions**	1 session	\
Can use after training	Can't use (use some)	**Use primary functions**	Can use (P and S)	Can use very well	Use some functions
Harshness	Lots	**Some**	None	\	None
Anthropometric difficulties	Prevents operation	If any, not prevent use	**None**	\	If any, not prevent use
Biomechanical difficulties	Prevents operation	If any, not prevent use	**None**	\	None
Task time	Slow	Quite slow	**Good**	Fast	Quite slow
Harshness	Lots	**Some**	Minimal	None	None
Unproductive actions task	**Some**	Minimal	None	\	Some
Unproductive actions device	Some	Minimal	**None**	\	Minimal
Disorientation	Some	**Minimal**	None	\	Minimal
Support-verbal	Lots	Some	**Minimal**	None	Some
Support-physical	**Some**	Minimal	None	\	Some
Task completion	50%	75%	**100% (>=90)**	\	75%
Comfort	Uncomfortable	Comfortable	**Comfortable**	Very comfortable	Uncomfortable
User attitude	Discontent	Content	**Happy**	Very happy	Happy
Responsiveness	Sometimes	Yes	**Yes**	\	Yes
Non-interference	Some interference	No interference	**No interference**	\	Some interference
Grip surface	Some slipping	No slipping	**No slipping**	\	No slipping
Device – positioned easily	No	Yes	**Yes**	\	Yes
Device – grasped easily	No	Yes	**Yes**	\	Yes
Device – manipulated easily	**No**	Yes	Yes	\	No
Controls – located easily	No	Yes	**Yes**	\	No
Controls – actuated easily	No	Yes	**Yes**	\	Yes
Neutral posture deviation	Harmful deviation	Non-harmful deviation	**Non-harmful deviation**	\	Non-harmful deviation
Effort	With effort	**Minimal effort**	No effort	\	With effort
Distraction	Distracted a lot	**Some distraction**	No distraction	\	Some distracton

Extended Usability Specification – User E: JM system (performance in bold)

Metric	Worst case	Lowest acceptable	Planned case	Best case
Initial test	Can't use at all	Use one function	Use some functions	Can use
Training	Lots of further instruction	Some further instruction	**Demo**	No instruction
Learning time	Infinite	4 sessions	3 sessions – (2 sessions)	1 session
Can use after training	**Can't use (use some)**	Use primary functions	Can use (P and S)	Can use very well
Harshness	Lots	Some	**None**	\
Anthropometric difficulties	Prevents operation	**If any, not prevent use**	None	\
Biomechanical difficulties	Prevents operation	If any, not prevent use	**None**	\
Task time	Slow	**Quite slow**	Good	Fast
Harshness	Lots	Some	Minimal	**None**
Unproductive actions task	**Some**	Minimal	None	\
Unproductive actions device	Some	**Minimal**	None	\
Disorientation	Some	**Minimal**	None	\
Support-verbal	Lots	**Some**	Minimal	None
Support-physical	**Some**	Minimal	None	\
Task completion	50%	**75%**	100%	\
Comfort	**Uncomfortable**	Comfortable	Comfortable	Very comfortable
User attitude	Discontent	Content	**Happy**	Very happy
Responsiveness	Sometimes	Yes	**Yes**	\
Non-interference	**Some interference**	No interference	No interference	\
Grip surface	Some slipping	No slipping	**No slipping**	\
Device – positioned easily	No	Yes	**Yes**	\
Device – grasped easily	No	Yes	**Yes**	\
Device – manipulated easily	**No**	Yes	Yes	\
Controls – located easily	**No**	Yes	Yes	\
Controls – actuated easily	No	Yes	**Yes**	\
Neutral posture deviation	Harmful deviation	Non-harmful deviation	**Non-harmful deviation**	\
Effort	**With effort**	Minimal effort	No effort	\
Distraction	Distracted a lot	**Some distraction**	No distraction	\

Extended Usability Specification – User Q: VR1 system (performance in bold)

Metric	Worst case	Lowest acceptable	Planned case	Best case	Now
Initial test	Can't use at all	Use one function	**Use some functions**	Can use	\
Training	Lots of further instruction	**Some further instruction**	Demo	No instruction	\
Learning time	Infinite	4 sessions	**3 sessions**	1 session	\
Can use after training	Can't use	Use primary functions	**Can use (P and S)**	Can use very well	Use primary functions
Harshness	Lots	Some	**None**	\	None
Anthropometric difficulties	Prevents operation	If any, not prevent use	**None**	\	If any, not prevent use
Biomechanical difficulties	Prevents operation	If any, not prevent use	**None**	\	If any, not prevent use
Task time	Slow	Quite slow	Good	**Fast**	Fast
Harshness	Lots	Some	**Minimal**	None	None
Unproductive actions task	Some	**Minimal**	None	\	Some
Unproductive actions device	Some	Minimal	**None**	\	None
Disorientation	Some	Minimal	**None**	\	None
Support-verbal	Lots	Some	Minimal	**None**	Minimal
Support-physical	Some	Minimal	**None**	\	None
Task completion	50%	75%	**100%**	\	100%
Comfort	Uncomfortable	Comfortable	**Comfortable**	Very comfortable	Uncomfortable
User attitude	Discontent	Content	**Happy**	Very happy	Content
Responsiveness	Sometimes	Yes	**Yes**	\	Yes
Non-interference	**Some interference**	No interference	No interference	\	Some interference
Grip surface	Some slipping	No slipping	**No slipping**	\	No slipping
Device – positioned easily	No	Yes	**Yes**	\	Yes
Device – grasped easily	No	Yes	**Yes**	\	No
Device – manipulated easily	No	Yes	**Yes**	\	No
Controls – located easily	No	Yes	**Yes**	\	Yes
Controls – actuated easily	No	Yes	**Yes**	\	Yes
Neutral posture deviation	Harmful deviation	Non-harmful deviation	**Non-harmful deviation**	\	Non-harmful deviation
Effort	With effort	**Minimal effort**	No effort	\	With effort
Distraction	Distracted a lot	Some distraction	**No distraction**	\	No distraction

Extended Usability Specification – User Q: JM system (performance in bold)

Metric	Worst case	Lowest acceptable	Planned case	Best case
Initial test	Can't use at all	Use one function	Use some functions	Can use
Training	Lots of further instruction	Some further instruction	Demo	No instruction
Learning time	Infinite	4 sessions	3 sessions – (2 sessions)	1 session
Can use after training	Can't use	**Use primary functions**	Can use (P and S)	Can use very well
Harshness	Lots	Some	**None**	\
Anthropometric difficulties	Prevents operation	**If any, not prevent use**	None	\
Biomechanical difficulties	Prevents operation	**If any, not prevent use**	None	\
Task time	Slow	Quite slow	Good	**Fast**
Harshness	Lots	Some	Minimal	**None**
Unproductive actions task	**Some**	Minimal	None	\
Unproductive actions device	Some	Minimal	**None**	\
Disorientation	Some	Minimal	**None**	\
Support-verbal	Lots	Some	**Minimal**	None
Support-physical	Some	Minimal	**None**	\
Task completion	50%	75%	**100%**	\
Comfort	**Uncomfortable**	Comfortable	Comfortable	Very comfortable
User attitude	Discontent	**Content**	Happy	Very happy
Responsiveness	Sometimes	Yes	**Yes**	\
Non-interference	**Some interference**	No interference	No interference	\
Grip surface	Some slipping	No slipping	**No slipping**	\
Device – positioned easily	No	Yes	**Yes**	\
Device – grasped easily	**No**	Yes	Yes	\
Device – manipulated easily	**No**	Yes	Yes	\
Controls – located easily	No	Yes	**Yes**	\
Controls – actuated easily	No	Yes	**Yes**	\
Neutral posture deviation	Harmful deviation	Non-harmful deviation	**Non-harmful deviation**	\
Effort	**With effort**	Minimal effort	No effort	\
Distraction	Distracted a lot	Some distraction	**No distraction**	\

Performance measurement – User E: VR1 system (performance in bold)

Table 1 – majority of measures

Measure	1	2	3	4	5
Ob – initial test	Can't use	**Use 1 function**	Use some functions	Can use	Can use well
Ob – training	Lots further instruction	**Some further instruction**	Demo	Verbal instruction	No instruction
Ob – learning-time	> 4 sessions	4 sessions	**3 sessions**	2 sessions	1 session
Obviousness mean					
Pre – use after training	Can't use	Use some functions	**Can use (P)**	Can use well (P+S)	
Pre – harshness	A lot	Some	**Minimal**	None	
Predictability mean					
Comp – Anthrop-diff	P.U or C.D	Some (not P.U or C.D)	Minimal (not P.U or C.D)	**None**	
Comp – Biomech-diff	P.U or C.D	Some (not P.U or C.D)	Minimal (not P.U or C.D)	**None**	
Compatibility mean					
Efficiency – task time	Slow	Quite slow	**OK / average**	Quite fast	
Efficiency – harshness	A lot	**Some**	Minimal	None	
Efficiency mean					
Effect – unprod.act.dev	A lot	**Some**	Minimal	None	
Effect – unprod.act.task	A lot	Some	Minimal	**None**	
Effect - disorientation	A lot	Some	**Minimal**	None	
Effect – support verbal	A lot	Some	**Minimal**	None	
Effect – support physical	A lot	**Some**	Minimal	None	
Effect – task completion	> = 50%	> = 75%	**> = 90%**	100%	
Effectiveness mean					
Satis – user observation	Uncomfortable	**Comfortable**	Very comfortable		
Satis – user com/react	Discontent	Content	**Happy**		
Satisfaction mean					
Biome – neutral.post.dev	Harmful deviation	**Non-harmful deviation**	No deviation		
Biome – effort	With effort	**Minimal effort**	No effort		
Engagement – distraction	Frequent distraction	**Some distraction**	Minimal distraction	No distraction	

Note: P.U. = prevents use; C.D. = causes discomfort

Table 2 – controllability measures

Measure	0	1
Responsiveness – feedback consistent and accurate	No	**Yes**
Non-interference – interferes with own use	Yes	**No**
Grip surface – prevents unintended slipping	No	**Yes**
Device access – positioned easily	No	**Yes**
Device access – grasped easily	No	**Yes**
Device access – manipulated easily	**No (I not easy for him, forceful movements)**	Yes
Control access – located easily	No	**Yes**
Control access – actuated easily	No	**Yes**

Note: 8 points available, device marked on controllability out of 8, for each user

Notes

Compatibility – biomechanical difficulties: his forceful movements causing overcompensation with I; can still use I, but takes some time to position cursor over small VE object; require more resistance to movement, and 2 I speeds.

Performance measurement – User E: JM system (performance in bold)

Table 1 – majority of measures

Measure	1	2	3	4	5
Ob – initial test	Can't use	Use 1 function	Use some functions	Can use	Can use well
Ob – training	Lots further instruction	Some further instruction	**Demo**	Verbal instruction	No instruction
Ob – learning-time	> 4 sessions	4 sessions	3 sessions	2 sessions	1 session
Obviousness mean					
Pre – use after training	Can't use	**Use some functions**	Can use (P)	Can use well (P+S)	
Pre – harshness	A lot	Some	Minimal	**None**	
Predictability mean					
Comp – Anthrop-diff	P.U or C.D	Some (not P.U or C.D)	**Minimal (not P.U or C.D)**	None	
Comp – Biomech-diff	P.U or C.D	Some (not P.U or C.D)	Minimal (not P.U or C.D)	**None**	
Compatibility mean					
Efficiency – task time	Slow	**Quite slow**	OK / average	Quite fast	
Efficiency – harshness	A lot	Some	Minimal	**None**	
Efficiency mean					
Effect – unprod.act.dev	A lot	**Some**	Minimal	None	
Effect – unprod.act.task	A lot	Some	**Minimal**	None	
Effect - disorientation	A lot	Some	**Minimal**	None	
Effect – support verbal	A lot	**Some**	Minimal	None	
Effect – support physical	A lot	**Some**	Minimal	None	
Effect – task completion	> = 50%	**> = 75%**	> = 90%	100%	
Effectiveness mean					
Satis – user observation	**Uncomfortable**	Comfortable	Very comfortable		
Satis – user com/react	Discontent	Content	**Happy**		
Satisfaction mean					
Biome – neutral.post.dev	Harmful deviation	**Non-harmful deviation**	No deviation		
Biome – effort	**With effort**	Minimal effort	No effort		
Engagement – distraction	Frequent distraction	**Some distraction**	Minimal distraction	No distraction	

Note: P.U. = prevents use; C.D. = causes discomfort

Table 2 – controllability measures

Measure	0	1
Responsiveness – feedback consistent and accurate	No	**Yes**
Non-interference – interferes with own use	**Yes (joystick button; base of J lifting up)**	No
Grip surface – prevents unintended slipping	No	**Yes**
Device access – positioned easily	No	**Yes**
Device access – grasped easily	No	**Yes**
Device access – manipulated easily	**No (mouse twist to side)**	Yes
Control access – located easily	**No**	Yes
Control access – actuated easily	No	**Yes**

Note: 8 points available, device marked on controllability out of 8, for each user

Notes

Predictability – use after training: can use joystick for some tasks, but requires physical help with others. Can use mouse for easier selection tasks, but finds it difficult to use for finer interaction tasks

Performance measurement – User Q: VR1 system (performance in bold)

Table 1 – majority of measures

Measure	1	2	3	4	5
Ob – initial test	Can't use	Use 1 function	**Use some functions**	Can use	Can use well
Ob – training	Lots further instruction	**Some further instruction**	Demo	Verbal instruction	No instruction
Ob – learning-time	> 4 sessions	4 sessions	**3 sessions**	2 sessions	1 session
Obviousness mean					
Pre – use after training	Can't use	Use some functions	**Can use (P + S)**	Can use well (P+S)	
Pre – harshness	A lot	Some	Minimal	**None**	
Predictability mean					
Comp – Anthrop-diff	P.U or C.D	Some (not P.U or C.D)	Minimal (not P.U or C.D)	**None**	
Comp – Biomech-diff	P.U or C.D	Some (not P.U or C.D)	Minimal (not P.U or C.D)	**None**	
Compatibility mean					
Efficiency – task time	Slow	Quite slow	OK / average	**Quite fast**	
Efficiency – harshness	A lot	Some	**Minimal**	None	
Efficiency mean					
Effect – unprod.act.dev	A lot	Some	**Minimal**	None	
Effect – unprod.act.task	A lot	Some	Minimal	**None**	
Effect - disorientation	A lot	Some	Minimal	**None**	
Effect – support verbal	A lot	Some	Minimal	**None**	
Effect – support physical	A lot	Some	Minimal	**None**	
Effect – task completion	> = 50%	> = 75%	> = 90%	**100%**	
Effectiveness mean					
Satis – user observation	Uncomfortable	**Comfortable**	Very comfortable		
Satis – user com/react	Discontent	Content	**Happy**		
Satisfaction mean					
Biome – neutral.post.dev	Harmful deviation	**Non-harmful deviation**	No deviation		
Biome – effort	With effort	**Minimal effort**	No effort		
Engagement – distraction	Frequent distraction	Some distraction	Minimal distraction	**No distraction**	

Note: P.U. = prevents use; C.D. = causes discomfort

Table 2 – controllability measures

Measure	0	1
Responsiveness – feedback consistent and accurate	No	**Yes**
Non-interference – interferes with own use	**Yes (base lifted, slight pitch interference)**	No
Grip surface – prevents unintended slipping	No	**Yes**
Device access – positioned easily	No	**Yes**
Device access – grasped easily	No	**Yes**
Device access – manipulated easily	No	**Yes**
Control access – located easily	No	**Yes**
Control access – actuated easily	No	**Yes**

Note: 8 points available, device marked on controllability out of 8, for each user

Performance measurement – User Q: JM system (performance in bold)

Table 1 – majority of measures

Measure	1	2	3	4	5
Ob – initial test	Can't use	Use 1 function	Use some functions	Can use	Can use well
Ob – training	Lots further instruction	Some further instruction	Demo	Verbal instruction	No instruction
Ob – learning-time	> 4 sessions	4 sessions	3 sessions	2 sessions	1 session
Obviousness mean					
Pre – use after training	Can't use	Use some functions	**Can use (P)**	Can use well (P+S)	
Pre – harshness	A lot	Some	Minimal	**None**	
Predictability mean					
Comp – Anthrop-diff	P.U or C.D	**Some (not P.U or C.D)**	Minimal (not P.U or C.D)	None	
Comp – Biomech-diff	P.U or C.D	Some (not P.U or C.D)	**Minimal (not P.U or C.D)**	None	
Compatibility mean					
Efficiency – task time	Slow	Quite slow	OK / average	**Quite fast**	
Efficiency – harshness	A lot	Some	Minimal	**None**	
Efficiency mean					
Effect – unprod.act.dev	A lot	**Some**	Minimal	None	
Effect – unprod.act.task	A lot	Some	Minimal	**None**	
Effect - disorientation	A lot	Some	Minimal	**None**	
Effect – support verbal	A lot	Some	**Minimal**	None	
Effect – support physical	A lot	Some	Minimal	**None**	
Effect – task completion	> = 50%	> = 75%	> = 90%	**100%**	
Effectiveness mean					
Satis – user observation	**Uncomfortable**	Comfortable	Very comfortable		
Satis – user com/react	Discontent	**Content**	Happy		
Satisfaction mean					
Biome – neutral.post.dev	Harmful deviation	**Non-harmful deviation**	No deviation		
Biome – effort	**With effort**	Minimal effort	No effort		
Engagement – distraction	Frequent distraction	Some distraction	Minimal distraction	**No distraction**	

Note: P.U. = prevents use; C.D. = causes discomfort

Table 2 – controllability measures

Measure	0	1
Responsiveness – feedback consistent and accurate	No	**Yes**
Non-interference – interferes with own use	**Yes (J button)**	No
Grip surface – prevents unintended slipping	No	**Yes**
Device access – positioned easily	No	**Yes**
Device access – grasped easily	**No (M and J)**	Yes
Device access – manipulated easily	**No (J)**	Yes
Control access – located easily	No	**Yes**
Control access – actuated easily	No	**Yes**

Note: 8 points available, device marked on controllability out of 8, for each user

Appendix M

- Questionnaire 1a: usability of VR1
- Questionnaire 1b: usability of VR1
- Questionnaire 1 results
- Questionnaire 2: usability comparison of VR1 and JM
- Questionnaire 2: results

Questionn

What do you think of VR1?

What movements can you do with VR1?

Using VR1

really don't like | don't like | OK | quite like | like | really like

very hard | hard | quite hard | OK | quite easy | easy | very easy

very tiring | tiring | quite tiring | OK | not tiring

very uncomfortable | uncomfortable | quite uncomfortable | OK | quite comfortable | comfortable | ver

Very boring | boring | quite boring | OK | quite fun | fun | great fun

Using handlebars

very hard	hard	quite hard	OK	quite easy	easy	very easy

Using stick

very hard	hard	quite hard	OK	quite easy	easy	very easy

What would you change about VR1?

Name:

Questionnaire 1b

Name:

What do you think of VR1?

Using VR1

Good?	✓ yes	X no	Like?	✓ yes	X no
Hard?	✓ yes	X no	Tiring?	✓ yes	X no
Comfortable?	✓ yes	X no	Fun?	✓ yes	X no
Handlebars hard?	✓ yes	X no			
Stick hard?	✓ yes	X no			

What would you change about VR1?

Q1 answers

	X	D	E	A	C
What do you think of VR1	Nice	OK	Good	Like it	
What movements – VR1	Hmm….nice	*	*	F, B, side-step, up/down	
Like using VR1	Really like	Yes (like)	Yes (like)	Quite like	
Hard Using VR1	Very easy	No (not hard)	No (not hard)	OK	
Tiring using VR1	Quite tiring	Yes (tiring)	Yes (tiring)	Very tiring	
Comfortable using VR1	Very comfortable	Yes (comfortable)	Yes (comfortable)	Very comfortable	
Fun using VR1	Fun	No (not fun)	Yes (fun)	Very boring	
Hard using handlebars	Easy	Yes (hard)	Yes (hard)	Quite hard	
Hard using stick	Easy	No (not hard)	Yes (hard)	Easy	
What would you change	*	*	*	Food, clothes, shoes, hat	
Further comments	Varied answers	Think his answers	Mostly his answers	Think she did find it fun	

	G	Y	Z	M	H
What do you think of VR1	Good	Good to work with	Alright, OK	OK	Moving
What movements – VR1	L/R turn, forward	Sideways, F, B, up/down	Stick, move, side-step	F/B, sideways, turn, up/D	*
Like using VR1	Really like	Really like	Quite like	Don't like	Yes (like)
Hard Using VR1	Very easy	Very easy	Hard	Hard	Yes (hard)
Tiring using VR1	Not tiring	Not tiring	Very tiring	Not tiring	*
Comfortable using VR1	Very comfortable	OK	OK	Quite uncomfortable	Yes (comfortable)
Fun using VR1	Great fun	Great fun	OK	Quite boring	No (not fun)
Hard using handlebars	Very easy	Very easy	Easy	Quite easy	No (not hard)
Hard using stick	OK	Very easy	Easy	Quite hard	No (not hard)
What would you change	Not sure	No	*	*	*
Further comments	Not much variation	Mostly his answers	Last 2 answers?		Not sure if understood

*

Note: user C was absent

Q1 answers continued

	I	J	L
What do you think of VR1	Really good	*	Good
What movements – VR1	U/D, move round, turn, B	Turn round, forwards	Anything
Like using VR1	Really like	OK	Really like
Hard Using VR1	Quite easy	OK	Easy
Tiring using VR1	OK	OK	OK
Comfortable using VR1	Very uncomfortable	OK	OK
Fun using VR1	Quite fun	Great fun	Fun
Hard using handlebars	Quite easy	OK	Easy
Hard using stick	Very easy	OK	Easy
What would you change	Quite like side, directions and up/down	*	Nothing
Further comments	Mostly her answers	Not much variation	

	K	N	Q
What do you think of VR1	Up/down etc	Good	OK
What movements – VR1	Turn, forward	Up/down, sideways	B, F, side to side
Like using VR1	Like	Like	Really like
Hard Using VR1	OK	Easy	Very easy
Tiring using VR1	OK	Not tiring	Not tiring
Comfortable using VR1	Quite uncomfortable	Comfortable	Very comfortable
Fun using VR1	OK	Great fun	Great fun
Hard using handlebars	OK	Very easy	Quite easy
Hard using stick	OK	Easy	Very easy
What would you change	Yes	No alright	Nothing
Further comments	Not much variation	Fine	Fine

Name:

Which do you like the best? Joystick and mouse same VR1

a little more more much more

Which is more easy? Joystick and mouse same VR1

a little more more much more

Which is more sleepy? Joystick and mouse same VR1

a little more more much more

Which is more comfortable? Joystick and mouse same VR1

a little more more much more

Which is more fun? Joystick and mouse same VR1

a little more more much more

Q2 answers

Question Pupil	Like best	Easier to use	More tiring	More comfortable	More fun	Further comments
X	VR1	VR1	VR1	VR1	VR1	Not vary
D	J+M	J+M	VR1	J+M	J+M	Understood
E	VR1	J+M	J+M	VR1	VR1	?
A	VR1	J+M	VR1	J+M	VR1	Think ?
C						
G	VR1	VR1	J+M	VR1	VR1	Understood
Y	VR1	VR1	J+M	VR1	VR1	Understood
Z	J+M	J+M	VR1	J+M	M	Understood
M	J+M	J+M	VR1	Same	J+M	Think ?
H	J+M	J+M	J+M	J+M	J+M	?
I	J	VR1	VR1	J	VR1	Think ?
J	VR1	VR1	VR1	VR1	VR1	Not vary
L	VR1	VR1	J+M	VR1	VR1	Understood
K	J+M	J+M	VR1	J+M	J+M	Think ?
N	VR1	VR1	J+M	VR1	VR1	Understood
Q	VR1	VR1	J+M	VR1	VR1	Understood
Totals-VR1	9	8	8	8	10	
Totals-J+M	6 (1 just J)	7	7	6 (1 just J)	5 (1 just M)	