Design of virtual environment input devices for people with moderate to severe learning difficulties – a user-centred approach

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ABSTRACT

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. The first stage of the study, '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 review. The next stage, before proceeding to concept design, was to identify any existing computer input devices that satisfied the device requirements. No satisfactory match was found. Concept design generated many new concepts 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. Evaluation of the chosen manufactured concept (VR1) followed. Objectives of this user-based assessment were to evaluate the usability of the new input system, to ascertain whether a User Centred Design methodology is a successful approach. The results of this study show that VR1 has greater usability than the more commonly used joystick and mouse for this user population.

1. INTRODUCTION

Significant research has been conducted in the application of virtual environments (VEs) for people with learning difficulties. For example, the virtual city has been developed to teach independent living skills to this user population (Cobb et al, 1998). More recently, Rose et al have investigated the use of VEs in vocational training of people with learning difficulties (Rose et al, 2000). In this study, 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. Research, which is rooted in developmental psychology theories, has indicated many benefits in the use of VEs for people with learning difficulties. For example, VEs: encourage active involvement in learning; avoid abstract thought; allow users to learn by making mistakes within a safe environment and provide access to previously inaccessible activities or places (Cromby et al, 1996).

Further research in this area has highlighted usability difficulties with the computer input devices, which are used to perform the VE navigation and interaction 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. The purpose of the research described in this paper was to examine the control of VE navigation and interaction tasks for young people with moderate to severe learning difficulties, in order to provide guidelines for the selection or design of usable VE input devices for this user population.

2. BACKGROUND

Studies on the most appropriate methods of VE control for people with learning difficulties have concluded that the joystick and mouse are the most suitable navigation and interaction devices respectively (Hall, 1993; Brown et al, 1997). The aforementioned research by Cobb et al (1998) showed that people with learning difficulties experience usability difficulties with these input devices. However, this research did not provide detail of the specific problems that were 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. An evaluation of the joystick and mouse was carried out with 14 school pupils with moderate to severe learning difficulties (Lannen et al, 2000). This evaluation concluded that it is important to consider the physical and cognitive abilities of the user population, the tasks to be performed 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 (see British Standard ISO 13407), 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 input device evaluation and supporting disciplines. The methodology is described as multi-disciplinary as the following disciplines either provide the tools for a particular step or will be consulted during the methodology: user-centred design; psychology; ergonomics; product design; engineering and human-computer interaction. An outline of the multi-disciplinary design methodology is shown in table 1. This paper will outline the first 3 steps of the methodology, before focusing on steps 4 and 5: ‘produce concept designs and prototypes’ and ‘carry out a user-based assessment’.

Table 1. *The multi-disciplinary design methodology.*

1.	Understand and specify the context of use
-	User, task and environment analysis (tool: usability context analysis (UCA))
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

3. UNDERSTAND AND SPECIFY CONTEXT FOR USE

3.1 Overview

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. The contextual data was gathered using the following tools:

- The context questionnaire from the Usability Context Analysis (UCA), available from NPL Usability Services (Thomas and Bevan, 1996)
- The Activity Analysis and Product Environment tools from the USERfit methodology (Poulson et al, 1996)

3.2 User analysis

21 pupils with learning difficulties, from the Shepherd School in Nottingham, were selected to form the VRD (Virtual Reality Device) user group. These pupils were selected by asking the teachers to recommend pupils whom: have the cognitive ability to understand the VEs; are not severely physically impaired and are interested in working with computers. The following characteristics of the user group were identified: skills and knowledge; cognitive ability; physical ability; perceptual ability; communication; behaviour and motivation. A selection of these characteristics is shown in table 2. Further details on the user data can be found in a previous paper by Lannen (Lannen *et al*, 2000).

Table 2. *Selection of user group characteristics.*

- Gender: 12 male, 9 female
- Age range: 7 – 19 (5 primary, 8 secondary and 8 from 16+ department)
- Skills & knowledge: used VEs before – 6; good joystick control – 9; good mouse control – 10
- Cognitive ability: majority have severe learning difficulties; some pupils have moderate to severe learning difficulties
- Physical ability: the pupils have moderate physical difficulties, including the following: fine-motor planning – 19; gross-motor planning – 18; finger dexterity – 6; co-ordination – 14
- Perceptual difficulties: auditory processing – 14; spatial awareness – 17; directionality – 15
- Communication: use Makaton signing – 21; short sentences – 9
- Behaviour: distractible – 5; require encouragement – 6

3.3 Task analysis

The objective of the task analysis was to develop a clear understanding of what the VE input device must do, so that a suitable device can be selected or designed that is fit for its' purpose. Three tools were utilised for this analysis: the UCA context questionnaire, a hierarchical task analysis and the USERfit Activity Analysis. The resulting data gathered is detailed in the context report (Lannen 2002).

3.4 Environmental analysis

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 Product Environment tool from the USERfit methodology was used to compliment the UCA data. This tool considers the wider implications of how the product will be supported. The environment data collected is detailed in the context report (Lannen 2002).

4. SPECIFY THE USER AND ORGANISATIONAL REQUIREMENTS

The final objective of this step was 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

4.1 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 et al, 1996). Table 3 details a selection of the contextual requirements. All of the requirements were listed in the requirement specification (Lannen 2002).

Table 3. *Selection of 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

4.2 Requirement research

It was important that the VE input device conformed to the relevant British Standards. Any of the requirements from the following standards that were not already covered by the requirement specification were added:

- ISO 9241-9:2000 – requirements for non-keyboard input devices
- ISO 9241-5:1999 – workstation layout and postural requirements
- ISO 9241-6: 2000 – guidance on the work environment

It was also important to ensure that the principles of interface design (from HCI literature) were covered by the requirement specification. These principles are: naturalness; consistency; relevance; supportiveness and flexibility. An examination of the requirement specification showed that these principles were already covered by the contextual and British Standard requirements.

4.3 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 3, 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. All of the device attributes were listed in the design specification (Lannen 2002). Table 4 details the device attributes that were specified to meet the design requirements in Table 3.

Table 4. *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

5. TECHNOLOGY REVIEW

The aim of this review was to identify any existing computer input devices that met the device attributes in the design specification or could be adapted to meet these attributes. 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. As this 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 the concept and prototype design step of the multi-disciplinary design methodology.

6. CONCEPT AND PROTOTYPE DESIGN

6.1 Concept design

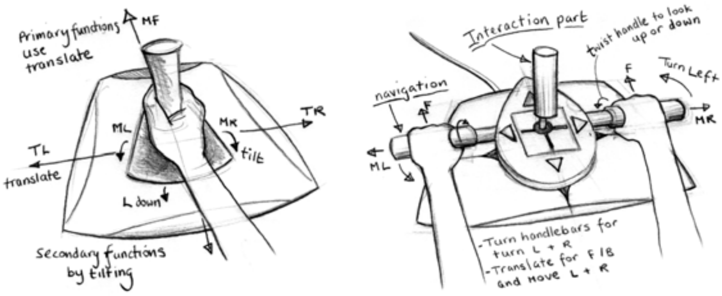
Concept design sets about producing a set of functional principles for how the product will work and a set of styling principles for the way it will look. A selection of the idea generation methods described by Baxter (1995), were utilised for concept generation, including lateral thinking (using analogies), the collective notebook and the theme board. The collective notebook was used to gather concept ideas from the usability team. The theme board is a collection of images of products that have the desired styling theme for the product under development and is used to inspire product styling.

6.2 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 feedback gained from this review included the following: predicted difficulties with the concepts; good features of the concepts; new ideas or features to try and recommendations to discontinue researching particular concepts. The concepts that developed from this review are depicted in Figure 1.

6.3 Concept selection matrix

The concept selection matrix (Baxter, 1995) was used to rank the final concepts against the selection criteria. The selection criteria, in this case, were the device attributes from the design specification. The results of this method showed that the best navigation concept was either the 'combined interface' (Figure 1) or the '2-hands control' (Figure 2a) and the best interaction concept was the 'joystick' (Figure 2b).



Tilting-joystick *Combined interface*

Figure 1. *Developed concepts from usability team review.*

a. *b.*

Figure 2. *a – 2-hands control; b – joystick*

One of the design specification attributes 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 concept and prototype design.

6.4 Embodiment design

This stage of the design process included the following: software development; electronic and mechanical design; materials specification and ergonomic design. Embodiment design resulted in the production of engineering drawings for prototype manufacture. Specific software was written for attaching to the evaluation VEs, so that the VE platform (Superscape) would recognise the inputs from the prototype. The electronic circuitry was designed for interfacing with the joystick (or games) port on a PC.

7. USER BASED ASSESSMENT

7.1 Introduction and objectives

Following concept and prototype design, the next step of the multi-disciplinary method was to conduct a user-based assessment of the developed VE input system. VR1 was to be compared against the JM system. The user-based observation for metrics method, outlined in the INUSE handbook of user-centred design (Daly-Jones, 1999), was utilised for this assessment. Evaluation objectives were:

- 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.

7.2 Experimental Design

The following hypothesis and conditions formed the 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.

Experimental condition: the user group is observed using VR1 to control navigation and interaction tasks.

Control condition: the user group is observed using the JM system to control VE navigation and interaction tasks.

7.3 Method

Participants with the following characteristics were selected for the study:

Participants: 14 subjects.

Gender: 10 male, 6 female.

Age range: 7-19

Cognitive ability: the majority of the pupils have severe learning disabilities. A few are bordering on moderate learning disabilities.

Physical ability: the pupils have moderate physical disabilities, including co-ordination, gross-motor and fine-motor difficulties. One pupil uses a wheelchair.

7.4 Tasks

A range of tasks were set in the Virtual Factory and Supermarket. Factory: entering building, putting on protective clothes, reporting oil, ladder, trolley and first aid kit, going upstairs, putting containers away and leaving the factory. Supermarket: Enter, select pineapples, oranges, tomatoes, milk cartons, cereal, tea and coffee, ice-cream and then go to check-out.

7.5 Usability Metrics

Guiding principles for the requirements of non-keyboard input devices were selected for usability attributes (ISO 9241-9 European Standard as follows: obviousness, predictability, consistency, compatibility, efficiency, effectiveness, feedback, satisfaction, controllability and biomechanical load.

7.6 Results

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 not significant.

Some 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 VR2, the efficiency and effectiveness, and hence overall usability, will improve.

8. CONCLUSIONS

The employment of the multi-disciplinary design methodology has resulted in the production of a VE input system that has greater usability than the more commonly used joystick and mouse. This finding could have relevance to other VE applications such as VEs for TBI patients (Davies et al, 1999) or for people with Asperger's Syndrome (Parsons et al, 2000), to enable selection and development of appropriate input devices to specific user populations. Continual application of the methodology could result in a database holding a range of suitable input devices for use by people with various disabilities using VEs. This database concept relates to the optimal VE access solution proposed by Brown (Brown et al, 1997): where the optimal solution would be to recommend a series of navigation and interaction devices that would allow people with a range of cognitive and physical disabilities to access VEs with ease and control.

9. REFERENCES

M Baxter (1995), *Product Design: Practical Methods for the Systematic Development of New Product,* Chapman & Hall, London.

D J Brown, S J Kerr and J Crosier (1997), Appropriate input devices for students with learning and motor skills difficulties**,** *Report to the National Council for Educational Technology, UK.*

S V Cobb, H R Neale and H Reynolds (1998), Evaluation of virtual learning environments**.** *Proc. 2nd European Conf. Disability, Virtual Reality and Assoc. Tech*, Skovde, Sweden, pp. 17-23

J J Cromby, P J Standen and D J Brown (1996), The potentials of virtual environments in the education and training of people with learning disabilities, *Journal of Intellectual Disability Research,* **40**, *6*, pp. 489-501.

O Daly-Jones, N Bevan and C Thomas (1999), *INUSE: Handbook of User-Centred Design*.: Serco Usability Services, Teddington.

R C Davies 1999, A practical example using VR in the assessment of brain injury**.** *Virtual Reality*, **4**,*1*, pp.3-10.

T L Lannen, D J Brown and H M Powell 2000, Access to Virtual Learning Environments for People with Learning Difficulties. *Proc. 3rd International Conf. Disability, Virtual Reality and Assoc. Tech***,** Alghero, Italy.

T Lannen (2002), A multi-disciplinary approach to the control of virtual environments for young people with moderate to severe learning difficulties. *Postgraduate Thesis, Department of Computing and Mathematics, The Nottingham Trent University*, 2002.

S Parsons 2000, Development of social skills amongst adults with Asperger's Syndrome using virtual environments: the 'AS Interactive' project*. Proc. 3rd International Conference on Disability, Virtual Reality and Associated Technology*, Alghero, Italy, pp. 163-169

D Poulson, M Ashby and S Richardson 1996. *USERfit: A practical handbook on user-centred design for assistive technology.* Tide European Commission

F D Rose, B M Brooks, and E A Attree 2000, Virtual reality in vocational training of people with learning disabilities**.** *Proc. 3rd International Conference on Disability, Virtual Reality and Associated Technology,* Alghero, Italy, pp. 129-135.

C Thomas and N Bevan 1996, *Usability Context Analysis: A Practical Guide, Version 4.03***.** Serco Usability Services. Teddington**.**

J D Hall 1993., Explorations of Population Expectations and Stereotypes with Relevance to Design. *Undergraduate Thesis*, Department of Manufacturing Engineering, University of Nottingham.