Designing a 3D desktop virtual environment for teaching

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Abstract: This paper describes the design process for prototyping a three-dimensional desktop virtual environment. The design model encompasses evaluation as the central part of the design process. Design implications derived from a formative evaluation are described in terms of navigation, object interaction and affordance perception. The design process is described in the context of prototyping an application for teaching safety information. The evaluation results suggest that user-centred design and attention to usability issues are not always sufficient to support the user for learning purposes. Although conventional human-computer interaction evaluation methods partially address the evaluation of three-dimensional applications, results showed that they are relevant for designing this type of teaching environments, particularly during early stages.

Key-Words: User-centred design, learner-centred design, desktop virtual environment.

1 Introduction
The central principle of user-centred design (UCD) is to create usable systems that are easy to learn and use [1, 2]. This design paradigm aims to facilitate the user’s interaction assuming that easier interaction will benefit the learner since the user has more cognitive resource available to concentrate on learning. In contrast, proponents of learner-centred design (LCD) view the learner’s needs as the central aspect of design [3,4]. Therefore, premises of both approaches should be assessed through the use of human-computer interaction methods in order to ensure usable applications for teaching and learning.

In this paper, the process for prototyping a three-dimensional (3D) desktop virtual environment (DVE) for teaching safety information is presented. The design of the DVE was based on a model that encompasses evaluation as the main part of the design process to assess interactivity and the learner’s needs of the learning environment. Requirements specification, prototyping along with evaluation studies of the 3D learning environment are presented.

The study reported in this paper is part of a more extensive research that investigated the elements that contribute for learning and retention of knowledge in three-dimensional virtual environments.

2 Design model
The design model described in this paper comprises three main stages, requirements specification, prototyping and evaluation. Figure 1 shows that the first stage of the process is to establish general requirements of the virtual environment (VE) in terms of the learner’s needs, which may evolve through the design process. Research activities such as a review of the literature in the field of virtual reality, theoretical frameworks, and technology constrains informed the design of the DVE.

Figure 1 also shows that prototyping and evaluation are cyclic activities performed during the development process. Prototyping involved activities for modelling static and animated components of the virtual environment, developing interactive design of the user-system interface and integrating the instructional content in learning scenarios. Heuristic and formative evaluations of the design as well as assessment of the instructional content comprise the evaluation stage.
3 Specification requirements

One of the main tasks in this stage was to gather information regarding the actual learning environment and how safety training was carried out in a physical setting. It was ascertain that existing safety training consisted of classroom-based instruction for all people that used chemistry laboratories. In addition, users of laboratories are required to assess the risk involved in every experiment that they carry out by completing a risk/assessment form. Further information was collected by reading safety literature, safety rules sheets, assisting in a safety induction class and interviewing safety personnel. With this information a number of training scenarios were identified, which were categorised into two main groups: laboratory safety precautions and emergency procedures. The former category was intended to be taught in a declarative form. The latter was to allow externalisation of declarative knowledge via students’ actions to execute steps of emergency procedures. In laboratory safety precaution scenarios the strategy was to enable students to recognize safety points and to conduct safety inspections in the virtual chemistry laboratory. For instance, in emergency procedure scenarios the intention was to recreate situations where the students would have to make decisions in coping with emergencies.

This activity helps to envisage scenarios at the initial design stage in terms of instructions and how to be represented in the teaching environment. For instance, the laboratory precaution scenario “Keep the laboratories and benches tidy”, was designed to depict untidy benches with broken glass. In this scenario, the learner must take actions to (a) tidy up and remove waste material to the appropriate bin, and (b) clear away at once all broken glass and put them into a special receptacle. Similarly, in the emergency procedure scenario “Actions on hearing the fire bell”, the learner must (a) leave the room or area; and then (b) she/he must go to an assembly area (away from the building entrance). These actions involve navigation through a smoked-filled area and removing obstructive objects from fire escape door in order to get to the assembly area. The analysis helped to establish a baseline to design the instructional content.

4 Prototyping

Prototyping stage was to investigate the most suitable representation of teaching scenarios by exploring and testing alternative design ideas through the use of rapid prototypes. Prototypes can convey more information for designers than written specifications [5] and can lead to more effective progress in a poorly specified design than using structured design methods [6,7]. Low technology prototypes such as drawings, paper-based sketches and storyboards were used to describe in a graphical form the visual features of the VE and to visualize interactive mechanisms (e.g., menus) in the virtual environment design. This type of prototypes were useful mainly for two-dimensional design, however, to explore design ideas in a three-dimensional space, computer prototypes were needed to create interactive events and animations, to integrate the user-system interface, to represent information in a 3D scene and to determine the limitations of desktop-virtual reality technology. The design of the virtual environment scenes was conceived as an incremental prototype and implemented with VRML due to its suitability for rapid prototyping and simple development.

The modelling of the DVE prototype consisted of two phases. First, an inert VE was modelled. Then, interactive objects and animated scenarios were developed. The purpose of the second phase was to animate the virtual laboratory and to create specific objects that reacted to the user actions.
5 Evaluation

The aim of the evaluation was to identify usability problems in the VE prototype and to obtain information about how well the VE supported the learning tasks. Early heuristic evaluations allowed proving design ideas along with usability problems. Potential usability problems included difficulties in navigation through the virtual environment, object interaction, interactivity issues with the browser interface and recovering from errors in carrying out tasks. For formative evaluation, additional tasks were designed to assess the functionality and effectiveness of the VE in supporting the user while they performed safety inspections and responded to situations. These issues included understanding of the training scenarios, object location and object identification.

Human-computer interaction methods were adopted in this evaluation. Quantitative and qualitative data were collected using cooperative evaluation [8] involving users and the designer of the VE to identify together usability problems, questionnaires and video-logging of the user-system interactions. As recommended by [8], a set of representative tasks of the virtual environment were selected and performed by users. For this purpose, participants were observed and encouraged to verbalise their impressions in using the VE. Although this technique can be seen as an intrusive method, it was very helpful at for assisting the participants and taking notes of critical incidents. A critical incident has been defined by [9], as an event that has a significant effect (positive or negative) on the user task performance or user satisfaction with the interface. In addition, quantitative and qualitative measures about navigational behaviour and interaction were obtained by screen recording of the user-system interactions. Furthermore, a questionnaire with closed and opened questions was used to obtain the subjective opinion of participants.

Subjects. Fifteen postgraduate students, ten males and five females, voluntarily participated in this study. Ages ranged from 26 to 35 years. They were either self-selected respondents to an e-mail announcing this study or were recruited by direct contact. Their experience in using computers ranged from 10 to 20 years with an average of 13.20 years of experience (SD - standard deviation = 3.23). They were classified into three categories according to their experience in 3D applications: no prior experience (eight subjects), novices (two subjects) and experts (five subjects). Prior experience in a chemistry laboratory was not necessary for this evaluation. However, nine subjects indicated they had worked in a chemistry laboratory with an average of 2.3 years experience (SD = 1.57) while the other six people did not have any familiarity with any chemistry laboratory.

Test environment. The usability evaluation was conducted in a room for usability evaluations configured with two desks, one for a workstation and one for recording equipment. Video and audio recording equipment consisted of a VCR, a TV set and a microphone. In order to video-tape the sessions the computer’s video signal was multiplexed to the VCR. The VE prototype was installed on a Silicon Graphics O2 workstation running at 120 MHz, with the IRIS operating system, a 21” colour monitor at 1200x800 resolution, 128 MB of RAM and standard desktop input devices (keyboard and mouse).

Experimental tasks. Four representative tasks that embodied all aspects of interaction, navigation issues and task needs were designed. The participants were asked to perform the following tasks: to determine the location of six objects; to identify two unlabelled flasks from the shelf and then move them to the nearest workbench; to navigate through the virtual laboratory and spot seven safety violations; and to cope with a minor fire.

Usability metrics. Effectiveness in this study related the goals of each task to the accuracy and completeness with which these goals were achieved. This metric was measured for each task by calculating: percent task completion; frequency of critical incidents; frequency of assistance required by the participant to proceed with the task; and the time taken to achieve the task.

Procedure. The aims of the study were presented in verbal and written form. They were also told that the study was not to test their abilities to interact with VEs nor their knowledge of laboratory safety but to find out problems in using the application. They were informed that their interaction would be videotaped and that the person conducting the evaluation would be present to assist them and to note down unexpected behaviour and interaction problems. Then, participants were given introductory training consisting of navigation in the virtual laboratory. After practicing for approximately 15 minutes (or the time required for them to feel confident), participants were provided with a sheet of paper describing the tasks to be performed. After they had read the task descriptions participants were asked to carry out four tasks in a limited time of 20 minutes.
6 Results
By analysing the video recordings, the comments made in the questionnaire and comments collected during direct observation, a number of usability problems were identified. A user event checklist was developed as an instrument for video analysis. Events that affected user performance were categorized into three factors such as navigation, object interaction, and affordance perception and fidelity (see Table 1).

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Navigation. It was found that system performance and features of the browser interface affected navigation. For example, jerky movements and lost of navigation control were caused by a poor response to the user’s inputs. The system did not process the user’s input fast enough, and as a consequence the user was often disoriented and lost control of navigation. Unclear functionality of the browser menu control was also an element that caused discontinuous navigation, along with the inconsistent responses of the browser. The constant switching between navigation directly on the VE and using the browser menu produced a number of critical negative incidents. Video recordings showed that the user was often confused while trying to select the appropriate roll-over to move forward and backward, turn around or move sideways. Further comments about navigation issues in general and the browser interface in particular, that participants disliked were expressed in the questionnaire.

Object interaction. Constraints imposed by conventional input devices such as mouse and keyboard for object manipulation in a three-dimensional space formed one of the main problem categories in completing the evaluation tasks. Moving objects in a direction perpendicular to the view plane was difficult without changing the user’s position in the VE. Change of visual perspective was necessary to see the position of objects with respect to other objects. The misjudgement of an object’s position in a virtual environment impeded completion of tasks. This task was also difficult to carry out because of the lack of visual feedback.

Affordance perception. It was clear that some objects were not well represented or modelled such as fire blankets, labelled flasks and fire extinguishers. Nevertheless, the video recordings showed that participants were generally able to understand the affordances of objects and they recognized scenarios that depicted safety violations. Recognition of interactive objects was facilitated by the visual feedback provided by the VRML browser as the mouse pointer changed in shape when it was placed over this type of object. Comments in favour of the virtual environment included realism of the VE, good representation of scenarios, impressive effects and novelty value.

Subjective issue. As mentioned before, participants’ subjective opinions regarding their experience in using the VE were obtained from a questionnaire. Modal responses confirmed navigation and object manipulation problems detected in video recordings. Subjective users’ opinions, in general terms, showed that the VE was enjoyable, easy to learn, well represented, easy but unnatural to navigate and provided a sense of presence and orientation.

7 Design implications
Based on results of the formative evaluation, new design ideas were explored and further examined by researchers with experience in HCI. A pilot study of the final version was also conducted with eight students from the Chemistry Department. The instructional material was also assessed by the person who was responsible for laboratory safety training. A summary of design implications is described in this section.

Restricted field-of-view. The issue relating to collision with objects that were out of the user’s field-of-view was difficult to resolve. The limited visual area of the VE is due to the physical constraints of the 2D display.
and the virtual camera, which restrict the user’s ability to use their normal field-of-view for navigation [10]. However, users were able to recover more quickly from collisions and to overcome obstructive objects more easily when the number of obstructive objects was reduced. An alternative solution was to provide auditory feedback or visual feedback, when the user collides with objects that were below the visible level of the field-of-view.

Object interaction. The original approach for interaction with the VE was to replicate to the greatest possible degree the performance of the user’s task in the real world, since natural interaction should be based on the application goal and tasks [11]. However, some metaphors make the interaction cumbersome and inefficient. A more realistic manipulation of objects was suggested to carry out tasks in as intuitive a manner as possible, for example, using ‘graspable’ objects rather than just ‘click-on’ objects (see Figure 2).

Fig. 2 Exploring symbolic manipulation through the use of embedded menus.

Affordances. Objects affordances are intrinsically related to their realistic representations (functional and visual) in the VE. To enhance graphical representation, objects were textured with image from photographs of real objects, instead of shades of colours. In order to enable rapid identification, objects were highlighted by altering their size when the mouse pointer was pointing to the object. With respect to unnatural behaviour of objects, simulated ‘gravity’ was added in addition to the capability to be dragged along the X, Y or Z axis.

Displaying embedded information. Similar to the technique used by [12] who utilized embedded symbolic information (text and audio) to display annotation in an immersive virtual environment, text and audio explanations were used to deliver semantic safety information about laboratory objects and scenes on panels. Short sentences explain laboratory precautions associated with typical laboratory objects or scenes. Further information can be heard by playing the audio clips in the panel. This combination allows the system to provide abundant information while reducing user fatigue from reading long passages. Some panels include images to provide pictorial details about objects that cannot be easily perceived in the VE or when it would be tedious to read a long textual description or listen to an extensive narration (see Figure 3). In order to make the relationship between objects and pertinent safety information closer, it was decided that annotations would exhibited near the spatial location of objects within the environment.

Fig. 3 Embedded panels provide textual, auditory and pictorial information.
8 Conclusion

The design and prototyping of a 3D DVE was described. The design consisted of a specification requirements, prototyping and evaluation as the central part of the design model. It has been seen that there are a number of interactivity issues that may affected teaching and learning in DVEs. Various design ideas were explored and evaluated through the use of conventional human-computer interaction methods and incremental prototype technique. This evaluation method revealed that the most important usability problems are associated with navigation, object manipulation and interaction.

Given the difficulties that most of the users had with direct manipulation, alternative design ideas were explored including symbolic manipulation based on conventional 2D menus. However, an expert review analysis indicated that external menus do not completely exploit the spatial metaphor and it would be more likely that they would prevent the sensation of ‘being’ in the VE. The alternative design was the use of embedded menus. Although manipulation of objects through embedded menus represented a good option for performing precise actions, the user was not directly involved in ‘doing’ the action and a number of sub-actions were necessary to perform even a simple task. It was therefore decided that, for effective learner-centred design, all information must be embedded in the VE and user-system interaction was kept as simple as possible.

Although conventional human-computer interaction evaluation methods partially address the evaluation of 3D VEs, results showed that they are relevant for designing this type of teaching environments, particularly during early stages. Further research is needed in order to investigate the assumption that easy interaction will benefit the learner and the direct implication for other VE aspects such as representation of information and task performance.

Reference