CVE Technology Development Based on Real World Application and User Needs

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Abstract

This paper argues that the development of Collaborative Virtual Environment (CVE) technology must be guided by application and end user needs. A collaboration is described between human factors and technological researchers based on observations of prototypes in use in a real world educational situation. The aim of the research is to develop a framework of design factors for the use of virtual actors in CVEs and to inform the development of underlying CVE technology.

The methodological approach followed involves the development of prototype virtual learning environments in a series of distinct phases of increasing sophistication. The environments are based on an ancient Egyptian game (senet) and are aimed at children at Key Stage Level 2 of the National Curriculum for education in England.

The paper shows how established two-dimensional multi-media technologies were used to develop robust prototypes which were then observed in use by children. Results from these phases have been used to guide the current phase of work. This involves the construction of a three-dimensional shared VE using the experimental Deva Virtual Reality system.

Index terms-- collaborative virtual environments, education, virtual actors, human factors

1. Introduction

Virtual Environment (VE) technology has provided a valuable new form of human computer interaction. However, the current understanding about VE design is poor [1] and there is still a long way to go until this level of supporting applications meets the users' needs. This is due to the fact that the development of the technology has been driven mainly by the challenge of developing the systems themselves and solving architectural problems rather than being based on applications development and users' needs.

DIVE [2, 3], MASSIVE [3, 4] and Diamond Park [5] are examples of social virtual environment systems in which distributed users can speak to each other and participate in joint activities. Currently these systems have been used mainly to investigate technical issues such as the system level mechanisms for supporting crowds in CVEs [6]. Technology development has also been driven by the need to improve rendering techniques, in order to maintain performance, and support photorealistic VEs and virtual human representations [7]. There has been a considerable amount of research on supporting issues like facial expressions and body language [8] to improve human communication.

MAVERIK [9] and Deva [10] are new VR systems under development in the Advanced Interfaces Group at the University of Manchester. Experience from developing the AVIARY VR system [11] a prototype multi-user Virtual Reality system for dealing with large-scale virtual environments, directed the design of MAVERIK and Deva. It highlighted the need for a different approach to spatial management and rendering in VEs (which are addressed by MAVERIK) as well as for techniques and tools for describing, managing and distributing behaviour in shared environments (which is the role of the companion system, Deva). Both systems have been developed from a primarily "architectural" perspective, attempting to overcome technological challenges in novel ways. However, the purpose of developing a technology is to serve the end user, rather than being an elegant piece of programming [12]. The human factors and user needs are important areas to be addressed in VE development in order for this technology to fulfil its potential [13, 14].

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This research aims to develop a framework of design factors relating to the use of virtual actors [15] in CVEs for learning. Virtual actors model human figures that move and function in VEs. They can represent software agents [16, 17] or humans (in which case they are known as avatars) [17, 18].

The role of virtual actors has been recognised in educational systems [19, 20]. The framework complements existing work by identifying interaction and communication factors relating to the use of virtual actors in CVEs used for learning. It also informs the development of the underlying technology according to user needs.

This paper focuses on the development of CVE technology based on observations of prototypes in use in a real world educational situation. The methodological approach followed involves the development of prototype learning environments in a series of distinct phases of increasing sophistication. It gives a brief description of the first two phases of work and shows how this has been used to shape the development of the third phase based on the Deva system. It describes the development of the current prototype, the issues to be investigated and the ways in which the work will be evaluated.

2. Methodology

2.1 Exploratory nature of the approach

The research approach has exploratory nature. Steed [21] distinguishes evaluation as belonging to either a scientific enquiry framework (concerned with the study of specific phenomena) or a usability engineering framework (concerned with measuring the effectiveness of a system). The studies being carried out are not evaluations but observations of what is going on. The work can thus be seen as belonging to the scientific enquiry framework.

Roussos [22] supports the need for such exploratory work which involves building novel learning applications and carrying out informal evaluations of them. Past studies have dealt with users with ready access to the technology. However, it is necessary to recognise the situated nature of the processes in collaborative learning. It is necessary to study a "real world" situation to determine the CVE requirements. Problems that determine the success or failure of a system can only arise in such a situation.

2.2 A "real world" application – Senet

The research uses a real world application based around Manchester Museum's Education Service [23]. The CVE is based on *senet*, an ancient Egyptian board game, from The Manchester Museum. The game allows both co-operation (in learning) and competition (in trying to win) to be studied. The social dimension of this game supports sociocultural theories of learning such as constructivism (learning by playing) [24, 25] and cognitive apprenticeship [26] as well as instructional methods of learning (some information is given to the players at the beginning of the activity in order to initiate the interaction). The impetus for collaborative learning comes from two main sources in the UK: the National Curriculum for education that places great emphasis on such learning and the National Grid for Learning (NGfL) [27, 28] proposed by the UK Government. The CVE is aimed at Key Stage Level 2 (~9-11 years old) of the National Curriculum for education in England.

A general description of the type of Collaborative Virtual Learning Environment (CVLE) to be studied can be created by synthesising models of VEs [1] and CVEs [6, 21] with models of classroom interaction [29]. A CVLE can be seen as consisting of three main elements:

1. ***entities***,
   the environment, objects within it, participants, groups of participants
2. ***actions*** between those entities,
   interactions with the environment and interactions with objects
3. the ***situation*** of the collaboration,
   the activity that is the subject of collaboration and pedagogy (the style of teaching/learning being used).

2.3 Iterative phased approach

One problem faced in this research is the vast number of factors involved in the construction of CVEs for learning. [1] has identified 46 design properties to be considered when designing VEs for usability. The number of factors increases dramatically when considering communication and collaboration issues in CVEs [20]. This makes it difficult to isolate which design decisions are responsible for the overall effectiveness of the environment. It is also difficult to identify the inter-play between various factors (e.g. the effects that usability issues have on pedagogic issues).

To simplify the study of design factors a phased iterative approach was adopted [30, 31]. Each phase structures the study of the CVE into a series of smaller studies. The research is divided into 3 main phases that differ in 3 main ways:

1. ***population***, the degree to which the environment is populated: semi- populated (the user sees other virtual actors present); fully-populated (the user can represent themselves via a virtual actor)
2. ***2D/3D***, use of a 2-dimensional environment simplifies issues relating to navigation and the way in which objects are manipulated
3. ***external/internal interaction***, whether users interactions take place outside or via the computer (Figure 1, 2).

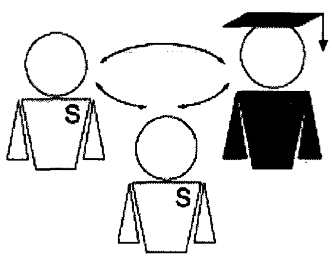

Figure1. Interactions external to the system ('S' student, 'T' teacher)

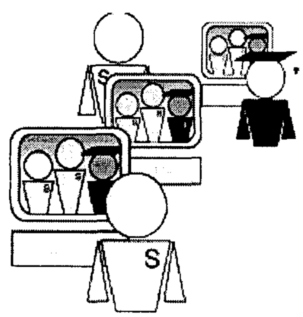

Figure 2. Interactions internal to the system ('S' student, 'T' teacher)

Each study represents a particular situation consisting of a subset of the range of factors in the CVE. Different prototypes are constructed for each study and observations made of them in use. The prototypes are based around the senet game. The phased approach provides several benefits. It provides the means of managing the complexity of factors by dealing with a manageable set of factors in each phase (e.g. 2D/3D and population). It allows the results of each phase to inform subsequent phases. In this way it allows requirements to be progressively identified. The use of more robust technologies allows the essential features of the situation (interactivity and social communication) to be studied with real users in a way not possible with more immature and inaccessible CVE technology.

The studies in the first two phases are aimed at deriving a rich set of qualitative information. From this a set of requirements can be identified and then used to inform the design of the third phase application. The work in the first two phases can be seen to be of a more exploratory nature, more like formative evaluation in contrast to the work in the third phase which will involve evaluation of a more summative nature.

3. First two phases

3.1 First Phase

Established two-dimensional multi-media technology has been used for the development of the first two phases of the research. The first phase prototypes (Figure 3), were examples of single display groupware [32], where interactions take place face-to-face in the real world external to the virtual environment (Figure 1). The prototypes were observed in use by the general public during an open week at Manchester Museum. Observations of school children were also conducted under more controlled conditions. Due to the nature of both activities and the environment that occurred note taking used for data collection.

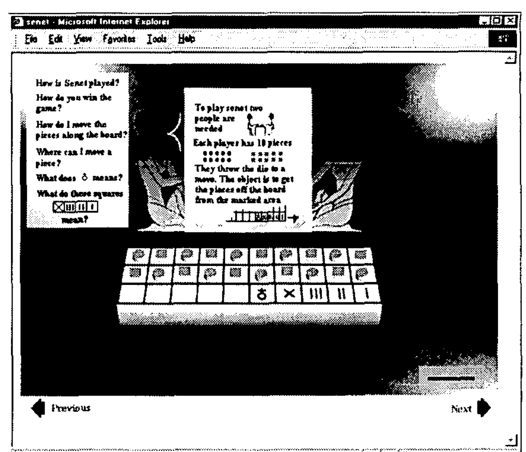

Figure 3. First phase prototype, single display groupware

The purpose of the first phase was primarily exploratory in nature. It gathered information about events in the real world game-playing situation and identified usability issues surrounding the prototype in order to inform the design of environments developed in subsequent phases. What stood out was mainly:

1. the rich range of interactivity and social communication that needs to be supported in CVLEs
2. the importance of the expert to be aware of and able to control even such a seemingly well structured activity as game playing.

3.2 Second Phase

In the second phase of work, prototypes were developed which took the form of conventional groupware systems (Figure 3, 4, 5). Participants were remotely located so interactions between them were internal to the computer (Figure 2). The prototypes were developed using 2D multimedia tools coupled with groupware technology typical of that used in education. The prototypes also introduced the concept of population to the environment. One prototype was semi-populated (the child could see a virtual actor representing the expert) (Figure 4) and the other two prototypes were fully populated (the child could also see their own virtual actor) (Figure 5, 6). Users communicated by typing text in chat boxes associated with their own (Figure 5, 6) actor or using a hand for pointing (Figure 4, 5, 6). Studies took place at a local school.

Data collection occurs by videotaping users, capture of text typed in chat boxes, and note taking. The Interactional Analysis[1] method [33] and Druin's[2] work [34] provided the foundation for the data analysis. The analysis results in a mixture of quantitative and qualitative findings. It deals with transforming vast amount of rich qualitative data in a quantitative form, that can be used to draw design principles for constructing CVEs for learning [35].

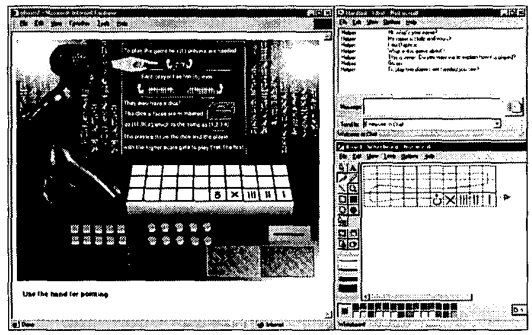

Figure 4. 2-D semi-populated, dialogue external to the game environment

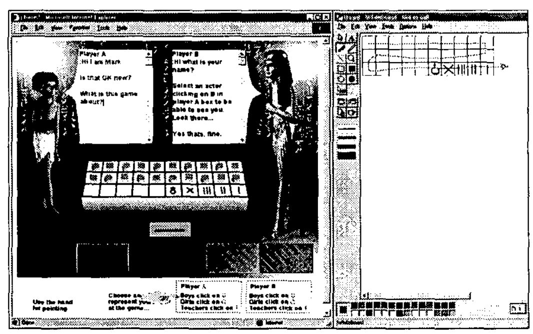

Figure 5. 2-D fully-populated, dialogue internal to the game environment

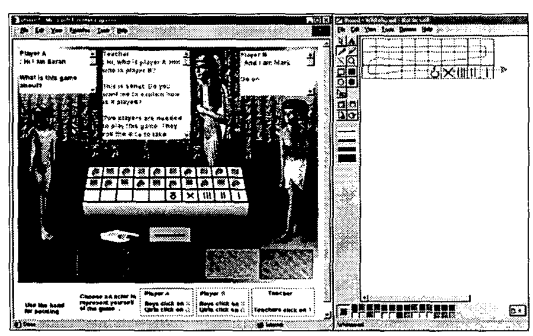

Figure 6. 2-D fully-populated, dialogue internal to the game environment, increased population

[1] Interaction Analysis is an interdisciplinary method for the empirical investigation of the interaction of human beings with each other and with object in the environment trying to identify routine practices and problems and their resources for their solution. The method is based on audio-visual recording for its primary records and on playback capability for their analysis. This provides a crucial ability to replay a sequence of interactions repeatedly for multiple viewers and for multiple occasions. This research borrows the Interaction Analysis pattern for the segmentation of the data to be analysed.

[2] Druin uses a framework for analysing qualitative data from observations of children and experts interacting with electronic educational applications, formed by the following criteria: time, quotes, activities, activity pattern, roles and design ideas.

The purpose of this phase was to explore issues surrounding the interaction being internal to the environment (communication via the tools in the prototypes) and the effects on the behaviour of participants. It indicated that problems arise because the established 2D collaborative technology limits the access of the expert to information about the situation. A comparison of the video of the expert and a video of the remotely located child showed such discrepancies.

Turn taking was particularly difficult. The expert was often unsure whether the child had completed their turn or was thinking over their actions. Technical problems (such as system lag) made this problem worse. To overcome these problems an informal turn taking protocol arose whereby a participant would place the mouse pointer in a particular area of the screen to signify turn completion. Another issue identified was the need to keep track of previous actions and dialogues.

The results from the first two phases have been mainly qualitative and served to elicit a set of requirements for the CVLE to be developed in the third phase. These requirements are currently being formulated into a framework of design factors concerning when using the CVLE in the third phase. The framework will include factors such as:

1. ***appearance*** (e.g. user's representation)
2. ***awareness***, what the actor perceives about the VE and situation
3. ***object manipulation***, ways in which the virtual actors uses objects (e.g. moving a piece in the senet game)
4. ***communication content***, the content of the communicative exchanges
5. ***communication modes***, the ways the virtual actors communicate (e.g. as text or as speech)
6. ***turn-taking***, i.e. communicating by taking turns (e.g. interrupting) or manipulating objects
7. ***role in situation***, this depends on the particular pedagogical style being followed.

4. Third Phase

The third phase studies focus on internal communication, interaction and collaboration processes in a 3D CVE. The studies in the third phase will be of a more evaluative nature. User studies of this environment will allow the design factors identified previously to be tested. Thus the development of the underlying technology is guided by user and real educational situations needs.

4.1 A brief description of Deva system

The Deva system aims to address a number of "large scale" issues VEs. These include management of large number of objects within an environment, large numbers of environments and applications co-existing, graphical complexity, and large numbers of geographically distributed users. Deva is architecturally a client/server system, with a cluster of servers forming a single virtual "world engine" that maintains the objective contents of all environments and their objects. Client viewer processes then connect to the world engine across the Internet in order to participate in the VEs. The MAVERIK kernel provides local graphics and input device handling for the clients, whilst Deva itself deals with the distribution and management of the behaviours of objects. Two novel features of Deva are:

1. its split between "objective reality" (managed in the server) and "perceived effect" (as presented by the viewers), and
2. its use of a high-level object orientated language for concise description of the nature of its environments and their contents.

Together, these features allow the system to explicitly manage the objects as they behave within and move between environments, and also to reduce network requirements by capitalising on aspects of human perception in order to "cull out" events in the VE that are never experienced (or are not important to) the users.

4.2 Conceptual design of the third phase

The main differences in this phase are:

1. it is a 3D environment
2. the environment is shared
3. the users can have control of individual input devices simultaneously
4. the virtual actors are fully functional (explained bellow)
5. the prototype that is being developed is fully-populated (Section 2.3).

The technology that is used is the DEVA 3D CVE system. Users have individual displays (a monitor, or a head-mounted display) and input devices (e.g. mouse or a 3D mouse) and the interactions between the users are internal to the environment. The environment contains artefacts related to the game like: the board, the pieces (that move in all (x, y) directions on a horizontal surface), the dice (that spins and gives random numbers from 1-4 when rolled) and the virtual actors' figures representing the participating users (Figure 7).

The users are represented by articulated virtual actors, allowing them to:

1. walk in the CVE, indicating the users' position in the space
2. select an object (if the virtual actor "within arm's reach" of the object then the avatar positions its hand correctly to "touch" it) or to pick a distant object by pointing (in which case a "laser pointer" from the hand indicates selection).

Current actors implemented in Deva support only static texture maps as faces, thus limiting the possibilities for facial expressions or "body language."

The communication is text based and external to the CVE prototype (similar to prototype 1 in the second phase). Although the second phase results showed a positive impact of the internalisation of the users dialogue it is difficult to implement such a system in a *fully* 3D environment. This is primarily due to limitations in screen resolution used to display CVEs, the effects of "anti-aliasing" which are more significant in 3D than in 2D, and also to the low-resolution depth or "Z" buffering provided by most 3D platforms. Although in principle there is nothing complex about managing text in a 3D environment, limitations of display technology mean that presentation of large quantities of readable text in CVEs is currently unrealistic.

The participant can obtain information about the game by using the dialogue box to ask the expert questions, or by reading the rules that appear on one of the walls of the environment. The expert can respond by typing text in the dialogue box or by pointing to rules on the wall or demonstrating something in the environment.

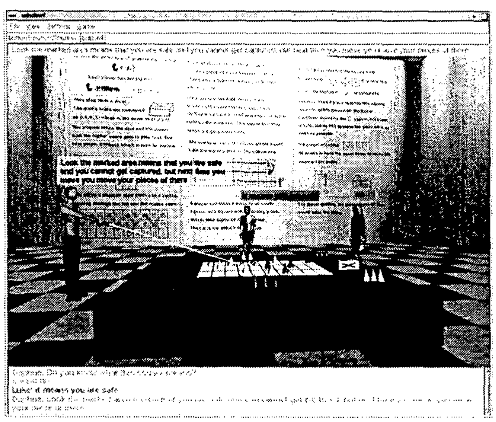

Figure 7. The senet prototype in Deva

4.3 Issues to be investigated

In the first two phases different means of communication (such as text, drawing and pointing) were used. Feedback from the second phase indicated that text worked satisfactorily apart from the system lag. The children commented that speech would provide a more direct way of communication and that they wouldn't have to worry about spelling. However, text is very important for the specific application, because a large set of rules has to be presented to the players. Additionally, skills such as reading and writing are of a significant importance in a learning environment and are strongly supported in the National Curriculum. It was also found that the chat boxes were useful because they provided a "transcript" of the dialogue that was used both by the expert and the children (e.g. scrolling back over an explanation) to kept track of previous actions and dialogues.

However, presenting text in VEs has not been developed to a sufficient level. Systems like MASSIVE support text that appears in a board inside the environment and some browsers (e.g. Active Worlds) support text that appears above the users' heads. These solutions are satisfactory only for a short text. It is almost impossible when a combination of text and illustrations has to be presented something very common for a learning environment. Observations of prototype 1 from the second phase (Section 3.2), indicated that an adequate solution can be provided by displaying the rules of the game on the wall. In the third phase rules will also appear on the wall (Figure 7).

Results from the first phase (Section 3.1), indicated the lack of use of the Egyptian virtual actor due to its inability to exhibit the behaviours shown by human experts. Previous work in the field has shown that actors with human like behaviours enhance the learning activity and increase children's motivation. Lester [36] describes a 2D educational environment in which two fully functional animated pedagogical agents (Herman and Bug) fly around, point out things of interest and provide children with problem-solving advice. In the second phase (Section 3.2), the virtual actors were provided with a hand to point with. This did aid the users' communication but it was treated mainly as a tool for communication separate from the virtual actor. It is expected that this will be improved in the third phase as the hands are parts of the limbs of the virtual actors, that communicate the user's actions (e.g. picking, moving and pointing objects).

Interactions in the CVE such as turn taking and control are of a great importance at this phase. The fact that the expert is remotely located from the child means that awareness cannot be achieved simply by looking at them. A comparison of the video of the expert (in which the expert voices the situation as they perceive it) and the video of the child, in the second phase, showed discrepancies in the expert's reading of the situation. The only cues available were the text appearing in the child's chat box or the movement of the hand pointer. The position of the mouse pointer gives some clue as to the other participant's focus of activity (e.g. if the other participant has moved the pointer to their chat box then it could be assumed that they are about to type in some dialogue). This is expected to be improved in the third phase as the virtual actors are capable of giving more visual clues of the actual interaction. However, giving visual clues about the users' intention to act is a subject of investigation for the third phase.

Turn taking became more difficult in the second phase. The NetMeeting tool only allowed one user to have control at a time, achieved by controlling the mouse pointer. However, an additional complicating factor was the lag in the system. One participant, seeing no apparent activity would take control of the pointer unaware (because of lag) that the other participant was in fact doing something. To overcome these problems an informal turn taking protocol arose during the studies whereby a participant would place the mouse pointer in a particular area of the screen to signify that their turn was completed. The Deva system supports simultaneous use of the input devices by any number of users. The problem that arises in this case is monitoring the individual user's activities. This is of significant importance in a learning environment, as the users need to be aware of the each other's actions in order to proceed and particularly for the expert who needs to know all the stages of the learner's activities. This is comparatively easy when face-to-face interaction occurs, but when the interactions are taking place remotely this is a difficult issue to deal with.

The biggest problem faced by the expert in the second phase was the number of times she was literally not in control in the environment. Whether it was due to lag or the child's lack of awareness of the expert's intended action it is not a situation that a teacher would want to see arise. This is an indication that one vital feature will be the ability to "freeze" the situation and take control. This is an issue supported by Deva system by virtue of its explicit management of the "Time" in an environment, allowing such notions as freezing, or even rewinding of "virtual time". Whether or not such apparently "unnatural" interventions in a teaching environment are appropriate, and exactly when such effects might be required in a 3D CVE is a matter for future investigation.

Another issue that needs further investigation is the effectiveness of the teaching techniques used. Thus different teaching styles are used, such as the reflection method (part of cognitive apprenticeship theory). For example, instead of giving direct feedback to children about their actions the expert ask one of the children to confirm that the other child's action was correct, e.g. "is this move correct", "what would you do if you were asked the same question". Such methods were used in the second phase and what stood out was that if system lag is involved it is very difficult to proceed and leads to frustration.

These application level issues all have implications that feed back into the architecture of the underlying CVE system.

4.4 Studies to take place

If possible the studies will be conducted by taking equipment into the school environment. This might be difficult due to the fact that the VE technology may not be easily portable. Two sets of studies will take place where the population will differ:

1. one child and an expert (played by a researcher)
2. two children and an expert. (played by a researcher)

At the start of the session the children will be shown how to use the system in order to start the activity. Different teaching styles will be used. Two ways of monitoring the activity will be used. The users will be video taped individually and all the activities and dialogues within the system itself will be recorded. This method of monitoring the activities has been decided upon after the second phase experience that indicated that the users had different perceptions of the actual situation. An after session discussion between the participants will follow.

As a starting point standard facilities (desktop monitor and mouse) will be used for the experiments. In future work it is planned to use other tools such as head mounted displays and a 3D mouse in order to examine the impact that these have on interaction and communication issues.

5. Conclusion

The paper has outlined a methodological approach to allow technology requirements to be studied from the point of view of users and the application. The previous phases of work have identified factors concerning the application and the problems of remotely located users. The studies planned for the current phase of work will allow these factors to be explored in more detail by using actual 3D CVE technology. The studies have more evaluative nature. The results of this phase will be used to refine the framework and determine how generic a set of CVLEs it will be applicable to. The findings will be of benefit not only in terms of human factors but also in shaping the direction in which the underlying technology itself develops.

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