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Networked Virtual Environments for Collaborative Learning

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Abstract

In this invited talk, I examine how the technologies of networking and desktop virtual reality can be used to enhance the quality of student learning. I use the C–VISions (Collaborative Virtual Interactive Simulations) system, developed at the National University of Singapore, as an exemplar system to help the audience appreciate the unique advantages that the technology affords for student learning as well as to highlight issues related to the design of networked virtual environments for collaborative learning. I begin by tracing the evolution of networked virtual environments and related work oriented toward supporting learning. I examine the "promise" of virtual networked environments for learning. I then outline the pedagogical basis of our work on the C–VISions collaborative virtual environment and briefly describe the C–VISions system. Next, I attempt to critically evaluate the C–VISions learning environment with respect to Brna's hypercube (Brna, 1998). Finally, I share some initial findings drawn from our first pilot study using C–VISions, and I conclude by pointing to future work.

Keywords: networked virtual environments, virtual worlds, collaborative learning, experiential learning

1 Introduction

Networked virtual environments have a history going back to the 1980s. Early systems (eg. SIMNET, DIS) reflect a strong military heritage. Other influences come from the field of network games (eg. Doom, Counter-Strike) and academic research (eg. PARADISE, DIVE). A more recent influence derives from MUDs and MOOs as well as other social chat systems that have incorporated a 3D graphics browser into the basic chat system (eg. Active Worlds, Community Place). The history of networked virtual environments has shown that such systems are inherently difficult to develop because they are, at the same time, distributed systems, 3D graphical applications, and real-time interactive software.

There are two main types of virtual reality (VR) environments today: fully immersive environments and desktop, semi-immersive environments. In fully immersive VR environments, users wear a head-mounted display. Motion trackers detect the movement and orientation of the display device so that as users walk and turn their head, the image shown on the display is appropriately updated to reflect the effects of the movement. In this environment, users typically also make use of a dataglove to interact with virtual world objects and system menus. In desktop VR environments, users utilize a regular RGB monitor or flat panel display that shows the 3D graphics of the virtual world on a 2D screen. They typically interact with the virtual world using the keyboard and a mouse. Other input devices, such as joysticks and 3D mice, may also be used.

Singhal & Zyda (1999) enumerate five common features of networked virtual environments. First, the 3D representation of shared virtual places allows users to have a shared sense of *space*. Second, by virtue of virtual persona represented as avatars in the shared places, users can enjoy a shared sense of *presence*. Third, as users locate themselves in shared places and interact with one another in real-time via the communication network, they experience a shared sense of *time*. Fourth, in such environments, users have at their disposal ways of *communicating* with one another: by typing text, by speaking, and by gesturing using their avatars. Fifth, users have a way to *share common objects* in the virtual worlds: either passively, by objects that provide a common frame of reference for experience, or actively, by objects with which users can directly interact.

To date, the most significant VR research related to education and learning makes use of fully immersive, non-networked VR. Winn and his colleagues at the Human Interface Technology Lab, University of Washington, Seattle, have been pioneers in this field (see, for example, Bricken, 1990; Winn, 1993). Their research has been rooted firmly in a constructivist-cum-constructionist mould, with students building their own immersive virtual environments and constructing an understanding of the content that their virtual environment represents. Winn (1999), for example, found that building a virtual environment improved low-ability students' understanding of the virtual environment's content, but the same was not true of high-ability students. More recently, *Project ScienceSpace*, headed by Dede at George Mason University, has investigated the use of multisensory immersive environments for the learning of complex scientific concepts related to physics (see, for example, Dede, Salzman, Loftin, & Ash, 2000; Dede, Salzman, Loftin, & Sprague, 1999). Empirical evaluation has focused on students' learning outcomes, their learning experience, their interaction experience using immersive VR, and interactions between these variables in relation to one another as well as in relation to learner characteristics.

In contrast to immersive VR, there appears to be no significant attempt to use desktop networked virtual environments for education and learning, prior to our research with the C–VISions (Collaborative Virtual Interactive Simulations) system. As part of the DEVRL (Distributed Extensible Virtual Reality Laboratory) Project, a collaborative research project between Lancaster University, Nottingham University, and University College London, Brna and his colleagues developed a virtual physics laboratory. Three virtual worlds were created—Cannon World, Table World, and Friction World—to help students learn physics. However, as reported in Brna (1998), DEVRL was essentially a standalone system that ran on SGI machines. In order to use it for collaborative learning between student dyads, two machines were used in distributed desktop mode while students, who were placed in the same room but facing away from each other, literally spoke aloud to one another. Hence, DEVRL does not quite measure up to the kind of systems described in Singhal & Zyda (1999). It appears that work on the virtual physics laboratory was prematurely curtailed due to funding limitations. Like Dede and his colleagues, Brna appeared to be primarily interested in the extent to which collaborative virtual environments (CVEs) could successfully support concept learning.

2 The "promise" of networked virtual environments for learning

A careful review of the extant research literature reveals that there are many reasons why networked virtual environments offer special promise for fostering learning.

The most unique and possibly also the most powerful characteristic of 3D virtual environments for learning is that they afford a first-person form of immersive or semi-immersive experiential learning. Too much of schooling today is based upon third-person knowledge, where students learn *that* or learn *about* something, without the opportunity to directly experience for themselves the thing that they seek to learn. The qualitative outcomes of third-person versus first-person learning tend to be very different. This difference is particularly evident in the documented research on students' understanding of physics concepts (McCloskey, 1983). A preponderance of third-person learning has meant that student learning outcomes are usually shallow. Students may possess a considerable amount of knowledge, but they possess little deep understanding; retention rates also tend to be low.

A first-person learning experience in virtual worlds has the advantage of giving users autonomy or control over their learning experience. Because of the way in which the virtual environments have been modeled and constructed, user actions always entail appropriate and immediate world feedback. This feedback provides a natural mechanism by which users can judge whether they have taken appropriate or correct actions in the virtual world. User-directed action and problem solving also foster a strong sense of ownership of the problem and its subsequent solution.

Learning in first-person experiential worlds naturally lends itself to multisensory learning that more closely reflects learning in the real world. While desktop VR environments are, in general, less able than fully immersive environments to support a rich range of sensory cues, the difference is primarily one of degree. Even with desktop environments, the use of joysticks, 3D mice, datagloves, and rich audio feedback can effectively create a multimodal interface and multisensory learning environment that is qualitatively different from using 2D learning software.

Because virtual environments lend themselves naturally to first-person learning, the learning environments constructed are usually based on the use of simulation. Simulation-based learning supports both active as well as interactive learning. Users are given control over critical elements of the environment. They are able to manipulate variables, change parameters, and test hypotheses. They can freely "play" with experiments that might be dangerous to conduct in the real world, and they can run the simulations as many times as they wish, taking time to focus on different salient parameters of the simulation each time it is run.

Simulation-based learning environments, in turn, present objects with natural affordances for supporting interaction. Thus, users are able to act directly upon virtual handles, levers, or controls in the environment, and the ability to do so creates a sense of presence—of "being there"—in the virtual environment.

Because virtual environments instantiate a synthetic replica of the objects and phenomena of interest, they serve an important representational function by helping to concretize and reify ideas. Indeed, clever use of representations may go so far as to make the otherwise unimaginable imaginable (as well as experienceable). For learners, this is a vital form of support for learning that can facilitate the formation of initial (possibly incomplete and not wholly accurate) mental models.

Three-D virtual learning environments naturally allow users to switch between egocentric, first-person experience of what they observe and exocentric, third-person experience of what is observable. This switching ability can be especially useful in facilitating alternative viewpoints or frames of reference on the same phenomena. One particularly powerful use of this perspective switching ability entails the adoption of what I might refer to as an endocentric viewpoint where students are able to enter directly "into" the world of the phenomenon itself (eg. a world of molecules; a world of electromagnetic fields) and "masquerade" as an element of the phenomenon. This use of VR leverages powerfully on the technology by realizing a form of learning that is not ordinarily possible for students to experience.

More broadly, multiple perspectives can also be supported through the use of multiple forms of representations. Ultimately, students need to be able to generalize from their learning experiences to form appropriate abstractions and rules related to knowledge of the domain they are learning about. Thus, it is possible to incorporate the use of other forms of visual information, such as graphs, as well as symbolic information in virtual environments so as to facilitate building a "bridge" between the contextual world of the experience and the decontextualized world of more abstract representations of knowledge. While the ability to include such representations and abstractions is not unique to virtual learning environments, it should be noted that providing such a facility to transition from the concrete to the abstract is vitally important for successful learning to take place.

So far, we have focused mostly on aspects related to virtual reality and representation. However, networked virtual environments possess one other important dimension: that of the network, which support communication, coordination of actions, and collaboration in learning activities between many different people at the same time. In short, networked virtual environments support interaction with and between people.

In a collaborative virtual environment, people are a very useful learning resource for one another. The ability to communicate through the technology, either by means of a text or audio chat system, allows users to engage in meaning making discourse. The fact that multiple users are engaged in a mutually shared context of experience makes discourse-based sense making a very natural human learning activity. Thus, if users are puzzled by an observation or fail to understand the meaning of a mutually shared video stream that they have been watching together, they will find it very natural to ask questions of others who share the same virtual world at that time. In addition, the ability to re-enact simulations and to compare common learning experiences over time is also likely to facilitate discourse that is of a more reflective nature.

Finally, the ability to both act directly on objects of interest and to talk directly to other users in the same virtual environment creates a highly engaging context of learning that can be very motivating, in an intrinsic way, for many students.

3 Pedagogical basis

In designing the C–VISions learning environment, we have been guided by the framework conveyed in Kolb's (1984) Experiential Learning Cycle (see Figure 1).

Kolb's framework appears, to us, to most effectively capture the essence of effective human learning. We believe that for human learning to be grounded in deep understanding, a concrete, experiential basis is necessary. Hence, students need to be given the opportunity to ground their learning in active, first-person experimentation which provides the basis for concrete experience. Concrete experience, in turn, provides a basis for reflective observation. Multiple observations, in turn, provide the basis for generalization and abstract conceptualization which, in turn needs to be validated or refined through further experimentation and contact with the world. Thus, we see that learning in general, and conceptual learning in particular, can be viewed as taking place in an ongoing, iterative cycle of stages until, at some point in time, a stable ideational state is reached. Notwithstanding this stable state, ideas and conceptual understandings are always subject to further perturbations that may lead to further revisions and refinements of a student's understanding.

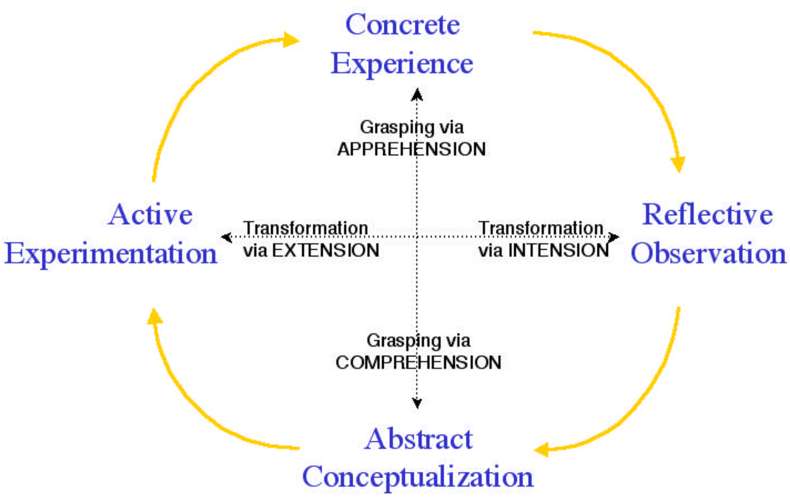

Figure 1: Kolb's Experiential Learning Cycle

4 The C–VISions learning environment

C–VISions is a networked virtual environment for collaborative learning. It supports student learning by allowing students to engage in collaborative virtual interactive simulations, coupled with a communication channel using either text chat or voice chat. It has been developed in the School of Computing, National University of Singapore. A free C–VISions client is available to any interested user; it can be downloaded via the Internet.

Figure 2 shows a screen snapshot of one of our simulation environments, the Vacuum Chamber. In this environment, we allow students to explore and learn about the physics of falling objects in a vacuum and in the same environment but containing air. The C–VISions environment provides for learning simulations in the domains of chemistry and biology as well, but we have chosen to begin with several physics simulations because we are acutely aware of the difficulties that many students have with understanding qualitative physics (see Gardner, 1991; McCloskey, 1983).

The C–VISions system interface contains two arrows pointing in opposite directions in the top-right corner. These arrows are used to slide out and slide away an HTML pane that contains a description of the simulation world, the tasks that users can engage in, and specific problems that users are asked to solve in a collaborative manner. A careful inspection of the problems shown in Figure 2 reveal that they are non-trivial. The problems were specifically designed to tease out students' qualitative understanding of free-falling objects in a vacuum and in an environment containing air. In particular, the problems are directed at helping students to disambiguate the effects of gravity, an object's mass, shape, and size, and air resistance acting on the object (if applicable) as it falls by comparing the time it will take two objects to fall and hit the ground.

In line with the discussion in Sections 2 and 3 above, the C–VISions learning environment has been designed to allow users to directly act upon objects of interest in the simulation environment. When the hand icon (see highlighted icon in Figure 2) is selected, users are able to interact directly with objects relevant to the simulation. As users move the mouse cursor over the 3D virtual world, "hot icons" are used to indicate objects that can be directly acted upon. The shape of the icon changes according to the kind of action that can be executed upon the object over which the mouse is positioned. In Figure 2, the "hot icon" is a hand cursor, indicating that the button on the remote controller can be clicked on. The buttons on the controller allow users to turn the vacuum on and off, select objects for dropping, drop objects, and reset objects onto the trap doors from which they fall.

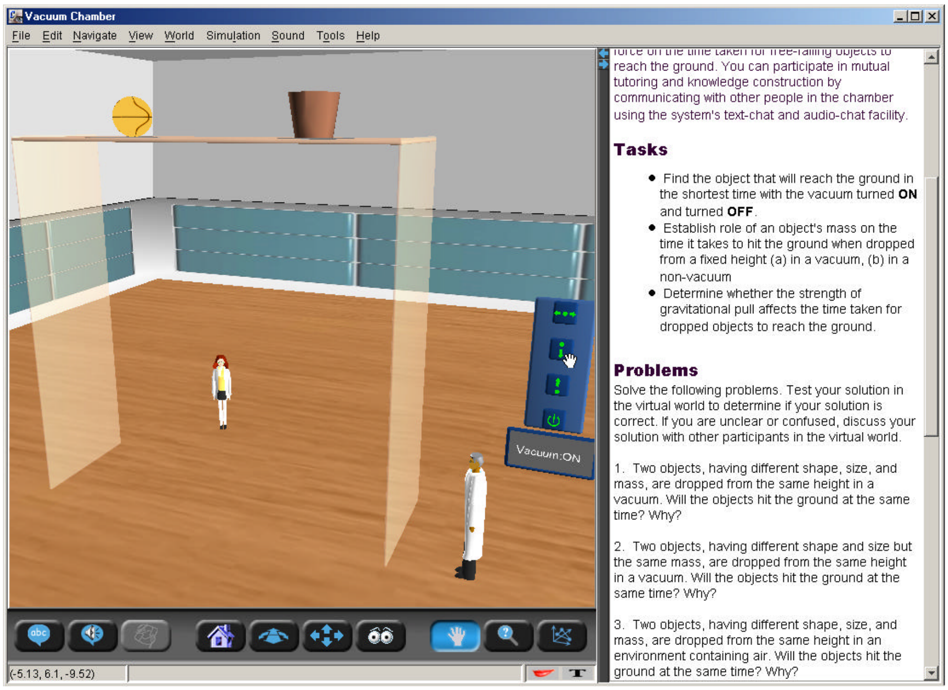

Figure 2: The Vacuum Chamber Simulation World

In order for users to wrestle with the given problems, they must be able to manipulate the properties of objects; for example, by changing an object's mass. To do this, students select the Inspector tool (the button showing a magnifying glass on the task bar) and click on the object whose property or properties they wish to modify. Doing so will throw up the Inspector window which allows users to examine the properties and property values of the object selected (see Figure 3). By clicking on the *Editor* tab, users can modify pertinent property values of the selected object.

Consistent with Kolb's experiential learning framework, C–VISions allows students to acquire concrete learning experiences through active experimentation. As students together "play" with the simulation, they engage in mutual problem solving activity as part of a search for a consensual solution.

A shared text chat or audio chat tool allows students to communicate with one another and to discuss their ideas and thinking in the context of collaborative problem solving. Importantly, the communication tool also serves as a channel through which users talk to coordinate their individual actions in the common problem solving space. Hence, discourse can be of two main types: learning discourse, oriented toward making sense of observations and directed to solving the problems given, and coordination discourse, directed toward coordinating joint activity in the virtual world.

Through conversation, students (typically) gradually evolve a consensual answer to the problems given and negotiate a shared understanding of the phenomena being studied. In order to arrive at this end state, they engage in extensive mutual as well as self explanation, building up a coherent account of their understanding. Over multiple runs of the simulation, students acquire multiple observations of the phenomena under study, and these multiple observations provide the basis for generalization and abstraction and the derivation of scientific concepts.

In practice, this "happy" state does not occur so readily as the road from experience to conception is a rocky one at best and fraught with multiple opportunities for misinterpretations of data and for misconceptions to arise. To aid the transition from experience to conception, C–VISions provides users with a visualization tool to assist them in viewing, reviewing, and focusing on salient simulation behavior to aid understanding and concept formation. Thus, in the Vacuum Chamber simulation world, the visualization tool allows users to plot graphs of height, velocity, and acceleration over time. These graphs can be played and replayed by all users for the most recently executed event in the simulation world. As the event is replayed in the mini-browser on the left (see Figure 4), the corresponding graph is plotted, in a synchronized fashion, on the right. The re-enactment of these events in the mini-browser can, in turn, be mutually discussed and reflected upon by students.

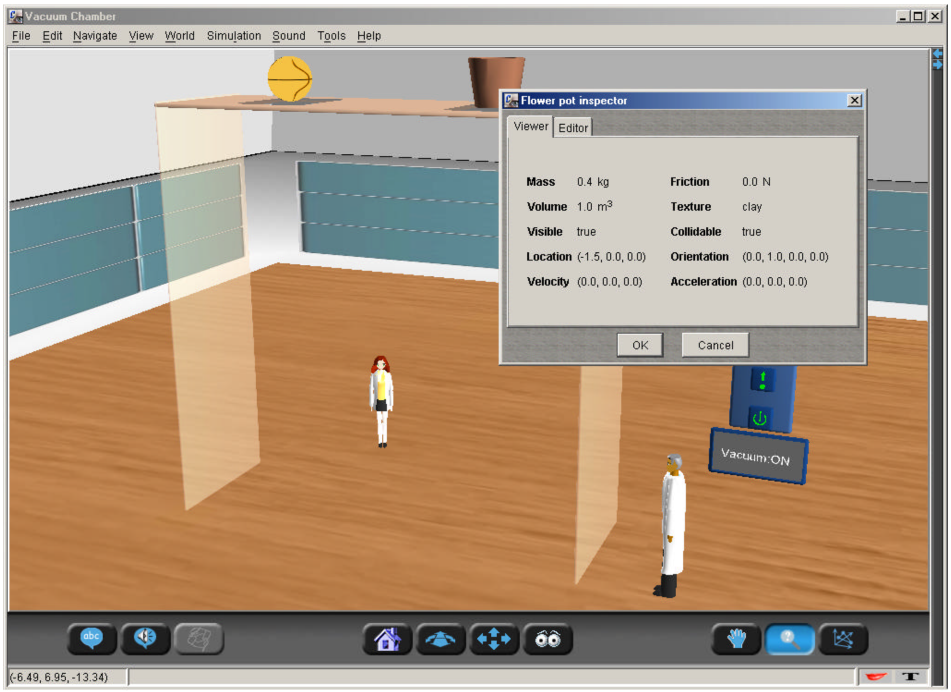

Figure 3: Vacuum Chamber showing the Flower Pot Inspector

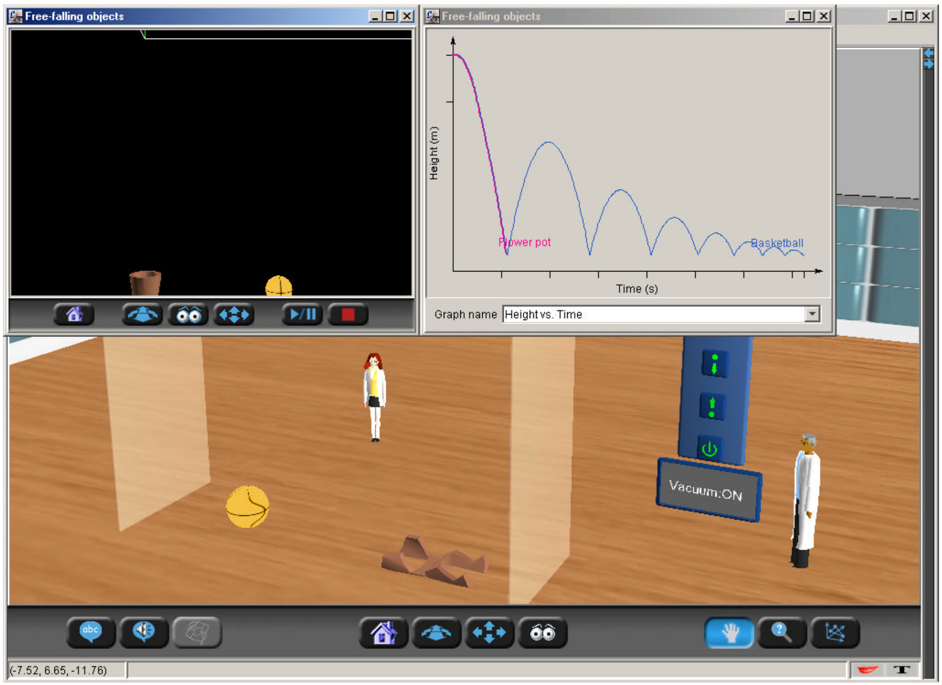

Figure 4: Vacuum Chamber showing the Visualization Tool

One of the hardest challenges that students face when attempting to learn Newtonian physics is that the world of sensory experience is not Newtonian (diSessa, 1986). By providing a visualization tool, we intend not only to provide students with a path from the concrete to the more abstract but also to make use of the visualization tool to shape and constrain students' understandings by having them relate the more difficult and more abstract representations (such as the graphs of velocity against time and acceleration against time; not shown here) back to the phenomena observed so that experience can become "colored" or seen through the lens of scientific theory.

There are many other issues that are relevant to the design of networked virtual environments, such as supporting navigation and interaction in the virtual world and supporting coordination and mutual awareness in joint tasks. Lack of space precludes our considering these issues further.

5 Critical reflection on the effectiveness of the learning environment

As a way to analyze and reflect on the potential effectiveness of the C–VISions learning environment (as opposed to evaluating the learning that takes place in the environment), it is useful to adopt the framework proposed in Brna's (1998) hypercube. In the context of networked virtual environments, Brna rightly recognizes that any framework for evaluation must include the social dimension of such environments because they are meant for multiple concurrent users. He therefore extends Whitelock's cube (Whitelock, Brna, & Holland, 1996) to encompass the social dimension of networked virtual environments. The hypercube consists of six dimensions. I shall refer to the first three dimensions, drawn from Whitelock's cube, as *individual* dimensions because they were proposed in the context of a single user of a virtual learning environment. The individual dimensions are (a) representational fidelity, which is further decomposed into (i) technical fidelity, the degree to which the technology delivers realistic renderings, (ii) representational familiarity, the extent to which the simulated environment is familiar to the user, and (iii) representational reality, the extent to which the world is possible; (b) immediacy of control, the ease and directness with which actions can be executed; (c) presence, an objective measure of the extent to which a person is "in" the environment.

I refer to the next three dimensions added by Brna as *inter-personal* dimensions because they deal with relationships between individuals. These dimensions are (a) social fidelity, which is further decomposed into (i) social familiarity, the extent to which the simulated social environment is familiar to the user, and (ii) social reality, the extent to which the social world is possible or believable; (b) immediacy of discourse, the extent to which the social medium of voice, gesture, etc. facilitates effective and interlocking dialog; (c) social presence, a measure of social richness with a sense of being a social actor within a medium.

In Table 1, I set out our assessment of the C–VISions learning environment with respect to the above framework. We make use of a three-category scale consisting of the terms *low*, *medium*, and *high*. It can be seen from the table that the learning environment fares quite well in terms of the framework. A lack of space precludes a more detailed justification of the ratings shown.

Table 1: Rating of C–VISions learning environment using Brna's hypercube

Individual dimensions

Representational fidelity	medium—high
Immediacy of control	medium—high
Presence	medium

Inter-personal dimensions

Social fidelity	medium—high
Immediacy of discourse	medium—high
Social presence	medium

6 Some pilot study findings

With the Version 1.0 release of C–VISions, we conducted a pilot study to obtain initial empirical feedback on the system in use. Three students (approximate age: 16 years old) used C–VISions for about 2 hours to work through the problems in two simulation worlds: the Vacuum Chamber and the Battleships World. As stated previously, the Vacuum Chamber deals with the behavior of falling objects. The Battleships World deals with the motion of projectiles. The students spent about 30 minutes on a training session to familiarize themselves with the C–VISions interface and controls before they tried to solve the simulation world problems.

One of the most striking observations we made was that the students initially experienced great difficulty working together on a common problem using the technology. They did not appear to recognize the need to and importance of explicitly coordinating their individual activities to perform the common task at hand. This observation suggests that, from a user interface design point of view, we need to consider how we might make students more mutually aware of what others are doing in the virtual environment so that coordination activity can flow more smoothly. A part of the difficulty we observed also arises from the fact that the students were not used to working collaboratively via technology; this was a completely new and novel experience for them.

After the hands-on portion of the study, we administered a questionnaire to the students. We report the results of three questions that we posed here. Question 2 elicited the students' agreement level to the statement "I now better *understand* physics concepts related to falling objects and projectiles in motion." On a 5-point scale ranging from strongly disagree to strongly agree, we received an identical response of 4 (ie. agree) from each student. Question 3 elicited the students' agreement level to the statement "I am now better able to *explain* physics concepts related to falling objects and projectiles in motion." On a 5-point scale ranging from strongly disagree to strongly agree, we received an average response of 3.67 (ie. between neutral and agree).

A further striking finding was the response to Question 5 which elicited the students' agreement level to the statement "I found using the system an *enjoyable way to learn*." On a 5-point scale ranging from strongly disagree to strongly agree, we received an identical response of 5 (ie. strongly agree) from each student. As part of the questionnaire, we also asked students to write a short reflection on their learning experience with C–VISions. We reproduce one of the reflection pieces below to give a sense of the impressions formed and the impact of the learning experience.

> *Using the system has made me more aware of how much Physics I don't understand. It has shown me that there are concepts that have to be grasped before fully comprehending the subject as a whole. The way this system works is unique, and it has helped me in the direction of understanding these concepts. The worlds are fun to work in and this is probably the reason why the whole process of learning was so much fun.*

Clearly, then, the students found that the C–VISions way of learning physics was a fun way to learn.

Finally, one consistent result across all three students is that, through using the system, they became acutely aware of how brittle their understanding of physics which they learned in school actually was. The cognitive dissonance created by the difficulty they experienced in working through the problems based on their level of understanding proved to be a powerful intrinsic motivator for their wanting to learn and their "demanding" the correct answers to the problems after the study.

7 Conclusions and future work

In this paper, I have reviewed the beginnings of the field of networked virtual environments and examined the ways in which these environments offer special advantages for the purpose of education and learning. I have articulated the pedagogical basis for the design of the networked virtual environment that we have developed, C–VISions. Using C–VISions, I have illustrated how networked virtual environments can be used to support simulation-based collaborative learning. I then reviewed the C–VISions system in light of the framework proposed in Brna's hypercube. Finally, I presented some of the findings from our pilot study of the system in use. Our findings are positive, and they have been very encouraging. They suggest that the use of networked virtual environments can help students to improve their understanding of physics and their ability to explain physics concepts. Not least, students find the use of such environments motivating for learning and enjoyable to learn with. Much further work remains to be done, both in terms of further system development as well as with respect to additional empirical studies of learning.

In closing, I wish to state that the field of networked virtual environments offers many opportunities for exciting research. We learned from our pilot study that, as a collaborative learning environment, students using the environment may not always possess the knowledge and understanding to advance the learning-based discourse in a direction that leads to coherent, scientific, knowledge building. To address this difficulty, we are actively working on the introduction of autonomous pedagogical agents into the learning environment. These agents will be embodied as avatars, like other users in the environment; they will also be able to communicate with other users either via textual messages or via spoken messages using a text-to-speech engine.

We plan to allow users to submit a photograph of themselves so that we can texture their facial likeness onto the heads of the avatar they choose, thus affording a level of "personalization" of users' virtual world representation. The longer term goal is to support a form of mixed reality in the virtual worlds, where the real and the synthetic begin to merge in a seamless fashion. What impact might such developments have for education and learning? We are unable to tell at present, but we believe that exciting times lie ahead.

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