# C-VISions: Socialized Learning through Collaborative, Virtual, Interactive Simulations

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## ABSTRACT

Today's cheaper personal computers with improved computational power have made the technology of networked desktop virtual reality environments accessible to typical end users, including students. This paper describes C–VISions, a collaborative virtual environment developed to support interactive and collaborative learning using virtual simulations. The research effort is grounded on the principles of active, experiential learning and constructivist/social constructivist ideas, with their attendant commitment to group sense making, discourse-based learning, and community building processes. The paper also provides an overview of the system's design and implementation. Finally, we explain the current status of the research effort and articulate plans for future work.

### Keywords

Networked virtual environments, desktop virtual reality, collaborative learning, interactive simulations, experiential learning, constructivism

## INTRODUCTION AND MOTIVATION

Educators and educational technologists often harbor visions of how computing technology might be leveraged upon to powerfully engage student learning. In practice, these visions are usually tempered by constraints related to the computational power of the hardware required and the cost of technology. Fortunately, rapidly increasing levels of hardware performance accompanied by falling costs has meant that students today have ready access to much more powerful personal computers than in the recent past. This development provides an opportunity for educators to push the technology envelope in pursuit of their vision.

One particular technology that is receiving greater attention in education is that of networked virtual environments (Singhal & Zyda, 1999). Such environments make prominent use of two system technologies: virtual reality and networking. While virtual reality (VR) technology has been available for many years, its application to the domain of education has been a specialist field limited to researchers with the resources to develop fully immersive VR applications. The rise of the Internet, however, has given rise to a new genre of distributed environments for chatting and socialization that include a desktop VR component, allowing users to share a three-dimensional (3D) virtual space. In this space, users are represented as avatars. They can navigate within the 3D worlds and interact with other users as well as virtual objects in the worlds albeit in fairly limited ways. Some of the most well-known systems of this type include *Active Worlds*, *blaxxun*, and *Community Place*. Damer (1998) provides a comprehensive, albeit somewhat dated, review of such virtual environments.

The goal of the C–VISions project is to harness networked desktop virtual reality technology to create a powerful and engaging collaborative environment for student learning. This technology was chosen because it is capable of supporting several important learning objectives. These objectives include experiential learning, simulation-based learning, inquiry-based learning, guided exploratory learning, collaborative learning, and socialized, community-based learning. The C–VISions environment seeks to foster these kinds of learning in the domain of science education, including physics, chemistry, and biology. We have chosen to focus on the desktop variant of virtual reality because it is readily accessible today. At the same time, it avoids the potential difficulty of motion sickness induced by the fully immersive virtual reality variant.

## RESEARCH BACKGROUND

As stated by Normand (1999), "the essence of collaborative virtual environments (CVEs) is the use of natural spatial metaphors, together with the integration of participants and data within the same and common spatial frame of reference" (p. 218). The most established, well-known, and successful research work involving VR for general education (as opposed to medical education) can be traced to the Human Interface Technology (HIT) Lab at the University of Washington, Seattle, and to *Project ScienceSpace* at George Mason University. Both these research efforts, however, are based on fully immersive VR that makes use of head-mounted displays and data gloves. At both locations, the technology has been deployed mostly in a stand-alone, non-collaborative learning mode. A less well-known example of the use of educational VR is Virtual Explorer from the University of California, San Diego, where the researchers have created an immersive, highly interactive environment for learning human immunology (Dean et al., 2000).

Findings from the HIT Lab suggest that students engaged in a virtual world learning environment found it fascinating and enjoyable. They were highly motivated to learn the concepts and skills necessary to design and model objects, with their associated behaviors, so that they could build their own virtual environments (Bricken & Byrne, 1993). A study by Winn et al (1999) also suggests that building a virtual environment improved low-ability students' understanding of the virtual environment content; however, it had no effect on high-ability students. Unlike the focus of allowing students to build their own virtual environments adopted at the HIT Lab, much of the effort at *Project ScienceSpace* focuses on using immersive VR to convey abstract scientific concepts and to aid complex conceptual learning (Salzman, Dede, Loftin, & Chen, 1999). *ScienceSpace* represents a systematic program of research that deals with physics. Three multisensory learning environments have been created: *NewtonWorld*, dealing with Newton's laws and the laws of conservation, *MaxwellWorld*, dealing with electrostatics, and *PaulingWorld*, dealing with molecular representations and quantum-molecular bonding. These science learning environments are unique in that they were designed explicitly to allow students to "enter into" the world of the phenomenon being studied, namely, the conservation of momentum, electric fields and potentials, and ionic versus covalent bonding. In this regard, the researchers have employed the technology in a sophisticated manner to allow students to experience phenomena that cannot otherwise be experienced in the real world.

Research that employs desktop VR for education and learning is more scattered and less established. One example is DEVRL, Distributed Extensible Virtual Reality Laboratory, a joint research project between Lancaster University, Nottingham University, and University College London. The objective of this project, which has probably ended, was to build a shared virtual physics laboratory. This work is not well reported. In contrast, a better publicized related research effort that also involves the three mentioned British universities is the COVEN (COllaborative Virtual ENvironments) project (Frécon, Smith, Steed, Stenius, & Ståhl, 2001; Normand, 1999). Unlike DEVRL, however, the COVEN research effort has a technology focus and is not oriented to applications for learning. Like DEVRL, it makes use of the DIVE toolkit as its development base.

Empirical evaluation of learning using desktop VR is still in its infancy. A weak example can be found in Mills & de Araújo (1999). In this example, the researchers sought to compare a desktop VR group and a non-VR group on the effectiveness of learning a management technique. They employed desktop VR in a stand-alone mode and hoped to exploit visualization capabilities afforded by the technology. Their study found no statistically significant difference between the two groups. Viewed critically, however, the researchers made poor use of the technology, and the study was poorly conceived and operationalized. It should be evident, therefore, that the field of desktop VR in education and learning remains open and requires focused and systematic research.

## TECHNOLOGY ASPECTS

When using desktop VR, the most prominent aspects of technology experienced are the 3D virtual world browser and the interaction style for interacting with the system. While 3D representation techniques and difficulties are fairly well understood from a computer science viewpoint, the design of an interaction style for 3D worlds still requires considerable research. In general, there are three types of interaction task that need to be supported: navigation, selection/manipulation, and system control (Bowman, Kruijff, LaViola, & Poupyrev, 2001). The design of an effective 3D interaction style will depend greatly on the domain in which the technology is applied and on the kinds of task that must be supported.

The introduction of networking technology to desktop VR allows the virtual worlds to be shared. Many technical hurdles must be overcome to implement a networked virtual environment successfully. Achievement of this goal, however, creates an environment where users can experience a shared sense of space, a shared sense of presence, a shared sense of time, a way to communicate, and a way to share objects and experiences (Singhal & Zyda, 1999).

There are other critical, but less apparent technology components at work in a networked virtual environment. A database is needed to support the persistence of object states in virtual worlds. Implementation of the technology also raises difficult issues relating to realtime, multi-user processing, the maintenance of world consistency across multiple client computers, the handling of concurrent events, and the design of a system architecture that will readily support scaling to a large number of concurrent users. In addition, the incorporation of audio communication and video streaming provide desirable, more advanced features that require implementation of realtime media streaming.

## PEDAGOGICAL BASIS

The design of C–VISions is rooted firmly on active, experiential learning (see, for example, Dewey, 1916/1980) and constructivist/social constructivist principles (see, for example, Fosnot, 1996). Boethel and Dimock (1999) provide an excellent critical review of how technology can be used to support knowledge construction. According to Doolittle (1999), the basic epistemological tenets of constructivism are:

*   Knowledge is not passively accumulated; rather it is the result of active cognizing by the individual.

*   Cognition is an adaptive process that functions to make an individual's behavior more viable given a particular environment.

- Cognition organizes and makes sense of one's experience; it is not a process to render an accurate representation of reality.
- Knowing has roots in both biological/neurological construction and social, cultural, and language based interactions.

In light of the above, the technology of VR is leveraged upon to instantiate active, experiential learning. We provide an environment where students can engage in focused science inquiry by running simulations, asking "what if?" questions, changing simulation parameters, and observing simulation outcomes. As Winn (1993) persuasively argues, immersive VR technology is especially empowering for learning because it supports a direct, first-person experience of learning. This argument holds true also for desktop VR environments despite a weakening of the multisensory dimension of experience.

Shared experiences that revolve around shared objects in a virtual world (for example, a rolling billiard ball or a streamed video clip) create a natural and authentic context for a discourse-based learning community. The context motivates students to articulate their ideas and understandings to one another, thus fostering an environment for peer-assisted learning and reciprocal tutoring. In C–VISions, both text-based chat and audio-based chat are supported to support discourse-based learning.

As researchers, we recognize the importance of helping students to make the transition from first-person, experiential learning to third-person, symbolic learning. To this end, C–VISions includes a set of collaboration tools comprising a shared electronic whiteboard and a shared mind-map editor. The shared whiteboard allows students to express and represent their ideas in symbolic as well as graphical terms. We also recognize the need to support abstraction and critical reflection. The shared mind-map editor serves this purpose. In addition, the C–VISions virtual world browser includes a visualization tool that allows students to call up graph plots of interesting phenomena on demand. Our intention and hope is that the supporting tool set will facilitate the needed transition from experience to mentation.

The Experiential Learning Cycle proposed by Kolb (1984) summarizes what we hope to achieve fairly well (see Figure 1). Active experimentation yields concrete experience that provides the basis for reflective observation which eventually leads to abstract conceptualization, and the cycle iterates. In the process, students' understandings are transformed both extensionally and intensionally while comprehension is grounded in apprehension.
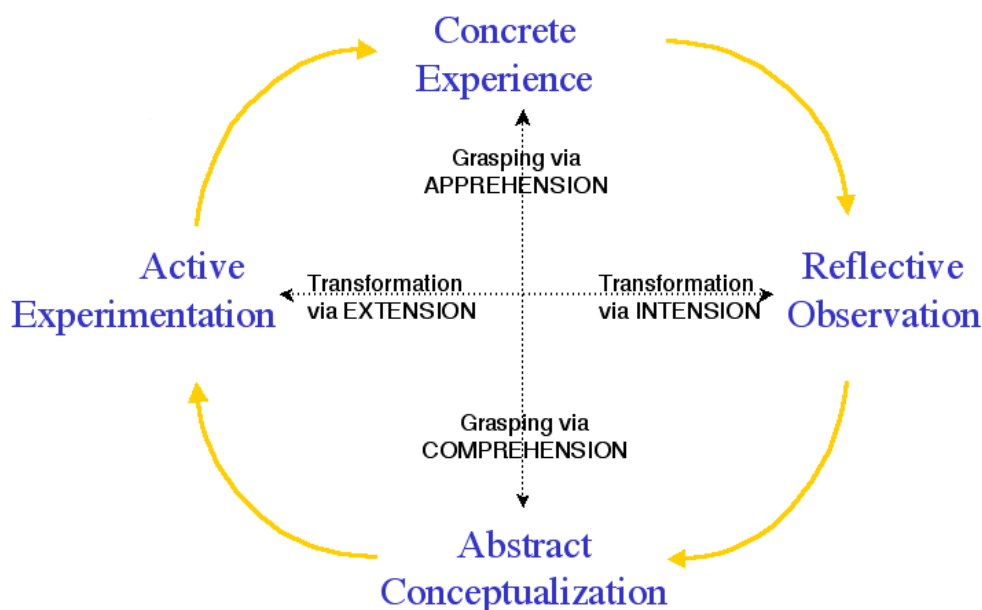


Figure 1. Kolb's Experiential Learning Cycle

Other authors have also highlighted the special advantages that can accrue from using VR for learning. Foreman (1999) values the sophisticated programmability of simulated objects and the simultaneous telepresence and collaboration of geo-distributed learners. He draws attention to three important features. First, avatar worlds are suited to developing actionable knowledge as opposed to knowledge for knowledge's sake. Second, avatar environments are leveraged effectively when they support learner-centered team work. Third, avatar worlds endowed with diverse learning resources support a discovery approach to education. The learning resources may include audio and video on demand, archives of images and schematics, conventional texts, search tools, objects that can be manipulated and queried, and programmed bots. Bricken (1990) extols the use of the computer as a reality generator, allowing the user to become a participant in the computational space where students are involved in activities that require explanation and extrapolation. Constant virtual world feedback provides a

continual validation of understanding in a very personalized form of learning. The technology is able to create a superset of reality and to allow students to learn through what-if scenarios. It provides a natural interface semantics, allowing students to act out their ideas rather than saying them. Students can also be empowered to participate in virtual world construction.

## THE C-VISIONS ENVIRONMENT

In this section, we provide a description of the C–VISions system in its current state of development. We use the description of one particular simulation world to highlight key features of the environment. We also explain the basic system design and implementation.

### System Description

The C–VISions learning environment is modeled as an interconnected virtual environment consisting of four levels. Level 3 is designated the Social World (see Figure 2). The Social World is a general community location for users to mingle and chat. Users are placed in this world when they first log in to the system.



Figure 2. C–VISions Social World

C–VISions focuses on supporting science learning. Level 1 of the environment, located below (virtual) ground level is the Chemistry World; level 2, ground level, is the Biology World. Level 4 houses the Physics World. At present, the chemistry and biology worlds are virtual worlds that contain no learning simulations. We have, however, developed three learning simulations in the Physics World. These are the Battleships World, the Vacuum Chamber, and the Billiard World. We chose to focus initially on the domain of physics because it is well known that students' understandings of physics phenomena are replete with misconceptions derived from real-world experience and intuition (see, for example, McCloskey, 1983).

The top-right corner of the virtual world browser shows two arrows pointing in opposite directions. These arrows are used to call up and to put away a separate display pane that contains information related to the world the user is currently in. This information is particularly useful for orienting students to the context and purpose of the learning simulation objects that they are interacting with. It also provides them with useful tips for interacting with the simulation and some science concepts for exploratory learning. Figure 3 illustrates the extended information pane of the Vacuum Chamber. The lips icon and the "T" (for Text) icon below the tool bar allow users to turn on/off system messages in (synthetic) voice mode and in text mode. Text mode messages are displayed in the horizontal strip to the immediate left of these icons.

Figure 3. Vacuum Chamber information pane

## Example World: Billiard World

The Billiard World is shown in Figure 4. It contains a billiard table with two balls and a cue stick for striking the balls. In the Billiard World simulation, students can learn about mass, velocity, acceleration, conservation of momentum, friction, and the coefficient of restitution.

### Navigation and change of viewpoint

The four buttons in the middle section of the tool bar at the bottom of the virtual world browser denote *Home*, *Navigate*, *Strafe*, and *Look* respectively. The *Home* button allows users to reset the view to a default viewpoint. The *Navigate* button allows users to move forward and backward and to turn left and right. The *Strafe* button allows users to move left, right, up, and down in a vertical plane. The *Look* button allows users to change their viewpoint—left, right, up, and down. The interaction style we have defined for the use of these buttons is click-and-drag. Several alternative interaction styles are possible. We plan to investigate the alternatives systematically at a later date, to identify which style is easiest to learn and which style is most efficient to use. Together, these four buttons allow users to alter their viewpoint and to navigate within the virtual environment. Collision detection has been implemented. Users can deactivate this feature, if they wish, from the Edit menu. To teleport from one environment to another, users can either navigate to the lifts located in the central lift shaft that connects the four levels of the virtual environment, or they can teleport via the *Navigate* menu in the system's menu bar.
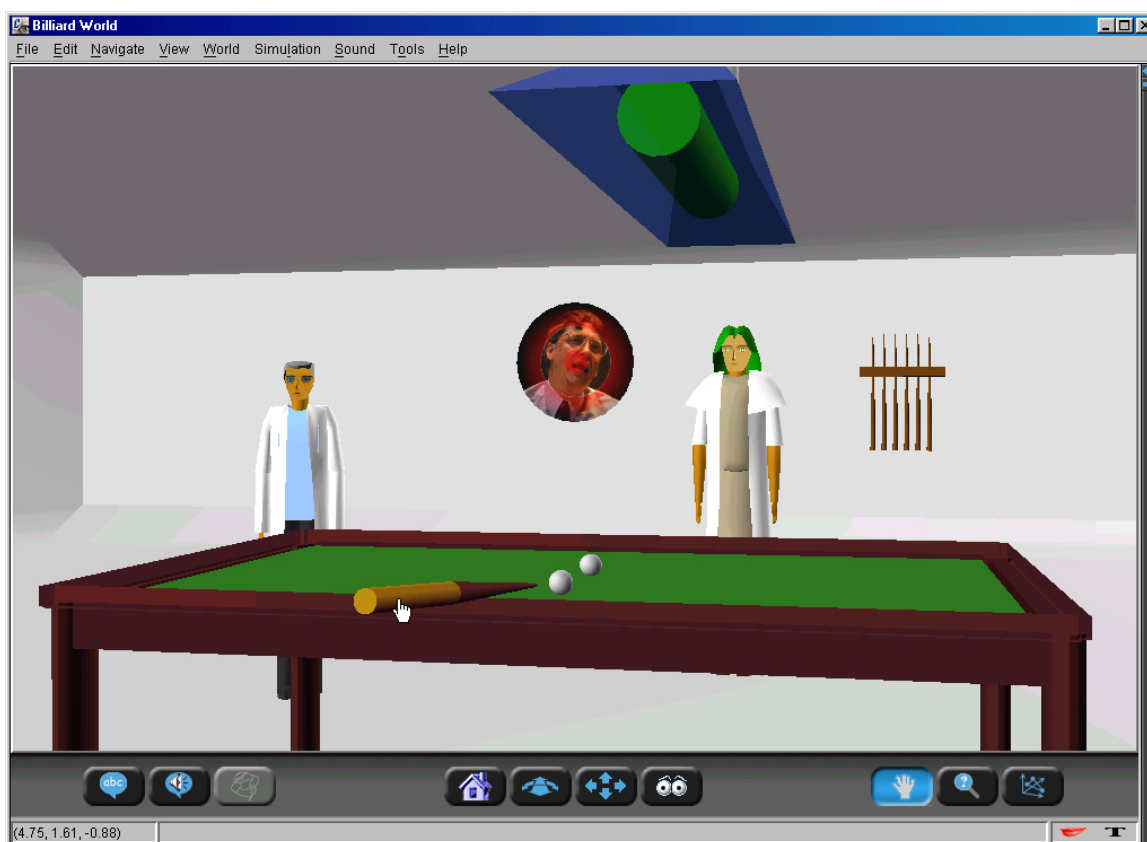
Figure 4. C–VISions Billiard World

### Object manipulation and interaction

Objects that can be manipulated in the virtual world are known as "live" objects. To enter object manipulation mode, users select the *Hand* icon (the highlighted icon in Figure 4). As users move the mouse cursor over the virtual world browser in this mode, the cursor icon changes to something semantically meaningful when the cursor is positioned over a "live" object. We refer to these cursor icons as "hot" icons because they provide feedback to users that some action can be immediately executed on the object over which the cursor is positioned. In Figure 4, for example, the cursor icon showing the hand with the pointing finger indicates that the cue stick can be used to strike the billiard ball at which the cue stick has been aimed. The highlighted rear half of the cue stick serves as a reinforcement of feedback that the stick can be thrust forward to hit the billiard ball at which it is aimed. Certain interactions with objects are more difficult to design than others because they require a set of sequential, discreet steps. Using the cue stick to strike the billiard ball is such an example. Users must first select the cue stick to indicate that it is the object that they wish to interact with (initially). The cue stick must then be aimed at the billiard ball the user intends to strike so that a coupling between the cue stick and the target billiard ball can be established. Finally, (the system state shown in Figure 4), the user must select the rear end of the cue stick and thrust it forward to strike the target billiard ball. Research on the design of 3D user interaction styles in desktop virtual worlds is in its infancy as suggested by Bowman et al (2001). This is an avenue of research that we intend to pursue.

### Object inspection and editing

C–VISions has been designed and implemented to allow users to inspect the properties of critical simulation objects in realtime and to modify the property values on the fly. This functionality is activated by selecting the *Inspect* button, denoted by the magnifying glass icon. (This feature is not illustrated due to lack of space.) Selection of the Editor tab foregrounds the pane that allows editable values to be changed. This functionality allows users to modify the value(s) of critical object properties, re-run the simulation, and observe the changes.

### Event visualization

C–VISions provides an event visualization function that allows students to replay the most recent simulation event and to view the plotting of graphs of that event in a synchronized fashion. This function is evoked by clicking on the *Visualization* button on the bottom right of the task bar. Figure 5 illustrates how the most recent event can be reenacted in the mini world browser on the left. As the billiard balls move as a result of one ball being initially struck by the cue stick, the graphs on the right hand side unfold. The figure shows a plot of distance traversed relative to time. Other graphs showing plots of horizontal and vertical speed and acceleration can be selected from the pull-down menu shown. The design intention is to

allow students to inter-relate and make sense of the different graph plots. It creates the context for inquiry and discourse-based learning about the phenomena of mass, velocity, acceleration, friction, and the conservation of momentum and helps to reify these abstract concepts. The provision of this tool is consistent with Bowman et al's (1999) advocacy of an "information-rich" virtual environment.
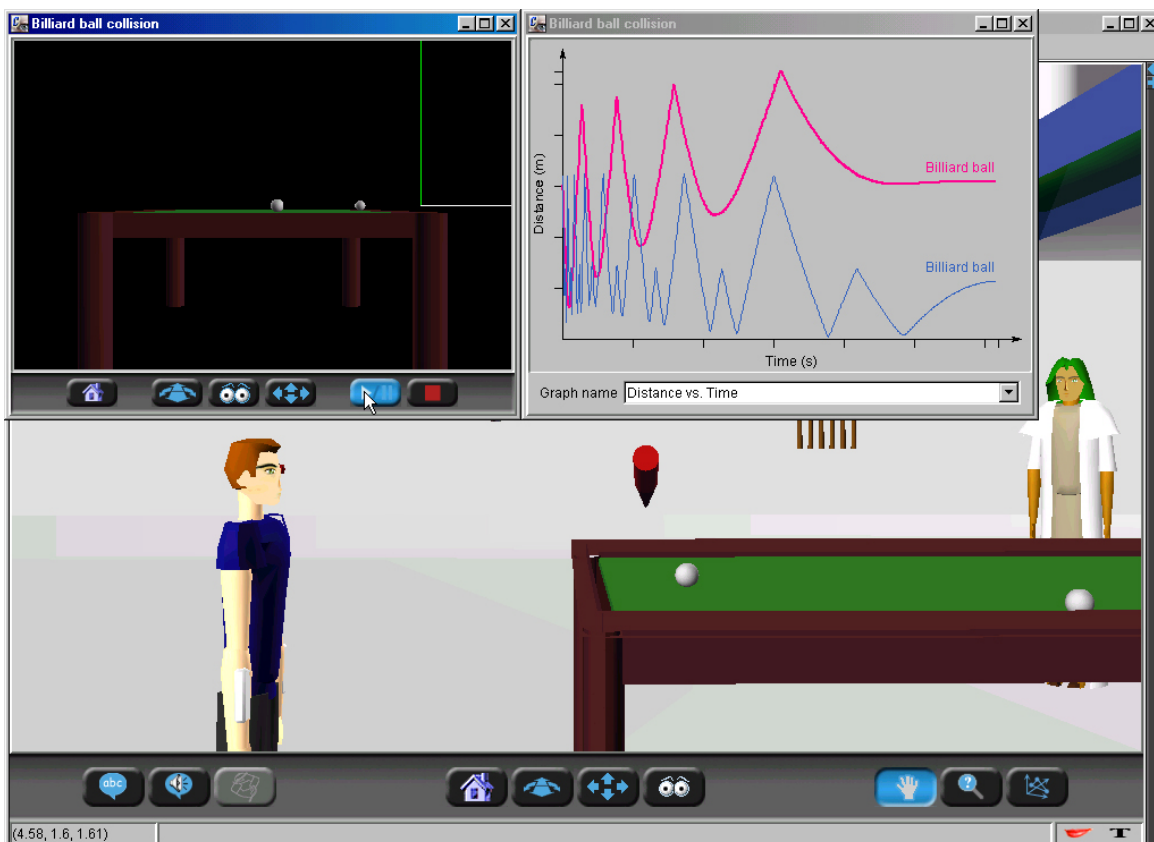


Figure 5. Event visualization in C–VISions

### Realtime video streaming

C–VISions allows students to share video resources with other students located in the same virtual world. To do so, students simply drag the movie file from the computer desktop onto a virtual screen in the virtual world. The video is then streamed to all computers and played concurrently in the browser of all students in the same world. This functionality allows video material to be used as a shared referent for sense making dialog. Of course, it can also be used for the purpose of entertainment in the Social World. Figure 6 illustrates the operation of realtime video streaming. Control buttons on the posts of the virtual screen allow the initiator of the streamed video to terminate and to replay the video.

### Communication

C–VISions supports student-to-student communication via text chat as well as audio chat. These functions are activated by the two buttons on the extreme left of the tool bar (see Figure 6). As suggested by Riva (1999), virtual reality is not only an environment for first-person experience, it is also a communication environment. The communication tools provided here are vital for discourse-based collaborative learning.

### Collaboration tools

Finally, C–VISions also incorporates collaboration tools to support higher level representation and organization of ideas. This function is activated by the third button, from the left, in the tool bar. The collaboration tools provided are a shared electronic whiteboard and a shared mind map editor.

Figure 6. Realtime video streaming in C–VISions

## System Design and Implementation

C–VISions has been designed from the outset to be a generic, object oriented software framework—the VISions[©] framework—that can be customized to different applications of the same genre. For example, it can be used to create military simulations or e-commerce applications. C–VISions is implemented entirely in Java and Java3D. Its design is based on the Model–View–Controller (MVC) architecture derived from the Smalltalk programming language. The Model component implements the virtual world, virtual objects, and the underlying laws that govern the behavior of the virtual objects. The View component implements the virtual world browser. It listens for events and renders them in the 3D browser. It also implements collision detection. The Controller component implements support for actions taken by the user in the virtual world browser.

The network component of C–VISions propagates virtual world events from every user to all other users in the same virtual world. There are two types of events. Semantic events are handled by TCIP/IP. User location change events are handled by UDP. To support object persistence, the state of all objects in the virtual world is constantly recorded onto a database. Conflict resolution for concurrent events has also been implemented.

The system-level flow of control and event propagation is depicted in Figure 7. When users interact with objects, the virtual world is informed of property changes made to the object. The virtual world updates the associated view and propagates these events to other client computers via the network to achieve synchronization of world state on all clients. Every event is tagged with the time of occurrence so that the order of events can be preserved and kept consistent across all clients at all times.

The virtual world (Model) on every client computer propagates events encapsulating changes to virtual objects. Upon receiving such events, the virtual objects update themselves and route the event to event listeners. The virtual browser (View) then interprets the events received from the virtual world and renders the updated geometric representations of all affected virtual objects. A more detailed explanation can be found in Chee and Khoo (2000).
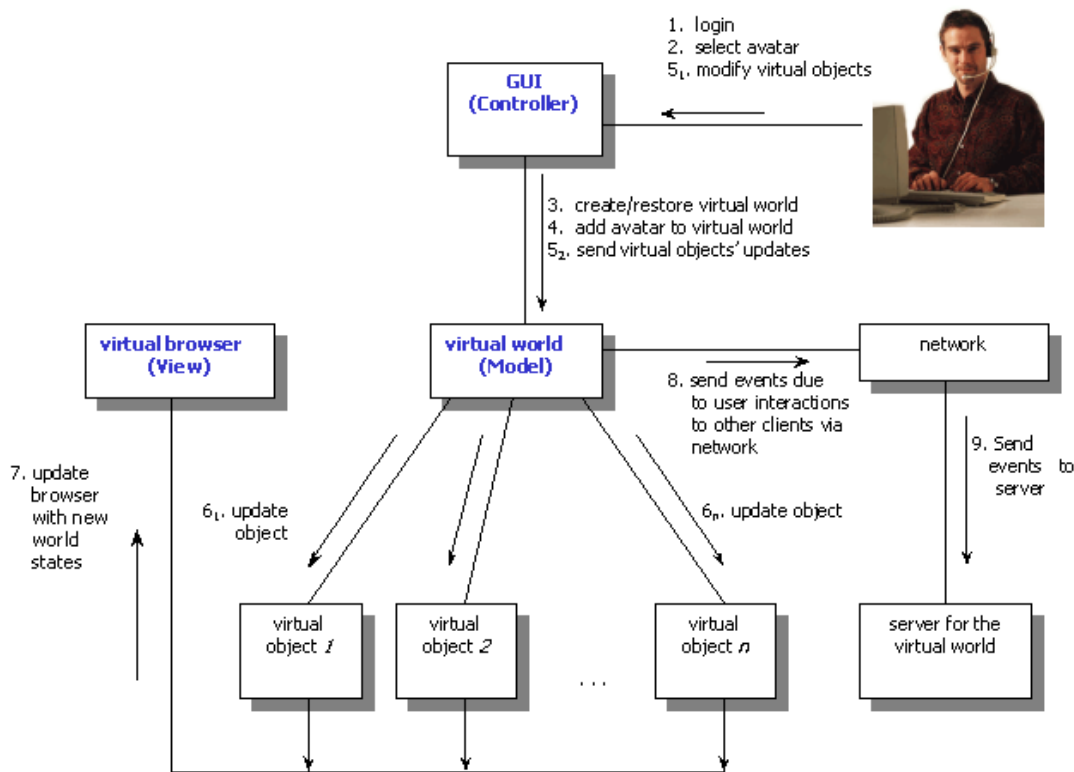
Figure 7. Schematic of control flow in C–VISions

## CURRENT STATUS AND FUTURE WORK

The C–VISions system has been in development for close to two years. This time frame gives a sense of the design and development effort involved. A beta Version 4 of the system was released in late June 2001, and a full release Version 1 was launched on 31 August 2001. The C–VISions client can be freely downloaded via the Internet. As the system was built to be accessible via the Internet and to be used by schoolchildren, both from home as well as from school, we have had to address many practical networking issues (eg. bandwidth and fast vs. slow connections, firewall and security restrictions). As it is not possible to instantiate the heterogenous Internet environment within a University network for testing purposes, we have been forced, of necessity, to rely upon incremental, public releases to test our system, and this is what we have done.

C–VISions needs several improvements. For example, the audio chat system needs to be enhanced to be on par with the text chat system in supporting virtual world localization; it is currently a global audio chat system. Our collaboration tools also need to be improved to better support participant co-awareness in coordinated learning activities. Active work is in progress on both these fronts. We also plan to support avatar animation and gestures in the near term.

For the future, we plan to continue populating the virtual environment with more simulation worlds. Upon system deployment, we plan to commence empirical research of how students learn with our system and to begin exploring relationships between the design of the system with the types of concepts or skills to be learned and with individual learner characteristics. On the user interface front, we plan to study desktop 3D user interaction styles. We also hope to create a modified version of the system that supports immersive VR. On the technology front, there are many challenging issues still to be tackled. Chief among these are the issues of scalability, distributed interaction support, failure management, and high-level semantic modeling for application of the system core to other domains. At the broader social and human-computer interaction level, we also wish to research issues related to the genesis and maintenance of virtual communities and to temporal and spatial dimensions of operating in 3D virtual environments.

## CONCLUSION

In this paper, we have set out our research work and vision for collaborative, simulation-based learning in desktop VR environments. Our focus on the desktop variant of VR has the benefit of making the technology widely accessible. From the perspective of pedagogy, our efforts are rooted firmly in active, experiential learning and the ideas of constructivism/social constructivism. We have explained the potential power of VR-based learning, especially in respect of shifting the learner's experience of education from a third person, disembodied perspective of knowledge to a first person, embodied perspective, using the technology to reify concepts to be learned, and providing the technology scaffolding to

help students transition from the experiential base of learning to the more symbolic, abstract, and reflective modes of the learned mind. In the process, we also hope to facilitate the development of communication, collaboration, and coordination skills in a socialized environment and to foster the building of learning communities.

## ACKNOWLEDGMENTS

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