The Evolution of Constructivist Learning Environments: Immersion in Distributed, Virtual Worlds

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To date, uses of information technology to enhance constructivist learning environments have centered on creating computational tools and virtual representations that students can manipulate. For example, many of the articles in this *Educational Technology* issue describe information technology instantiations of Perkins' (1991) classification of constructivist paraphernalia: information banks, symbol pads, construction kits, phenomenaria, and task managers. As learners interpret experience to refine their mental models, computational tools that complement human memory and intelligence are made available. In parallel, transitional objects (such as Logo's "turtle") are used to facilitate translating personal experience into abstract symbols (Papert, 1988; Fosnot, 1992). Thus, technology-enhanced constructivist learning currently focuses on how representations and applications can mediate interactions among learners and natural or social phenomena.

However, the high performance computing and communications capabilities driving the deployment of the National Information Infrastructure create a new possibility. Like Alice walking through the looking glass, learners can immerse themselves in distributed, synthetic environments, becoming "avatars" who vicariously collaborate and learn-by-doing using virtual artifacts to construct knowledge (Walker, 1990). Evolving beyond technology-mediated interactions between students and phenomena to technological instantiation of learners themselves and reality itself shifts the focus of constructivism: from peripherally enhancing how a student interprets a typical interaction with the external world to "magically" shaping the fundamental nature of how learners experience their physical and social context.

Immersing Learners in Distributed, Synthetic, Constructivist Worlds

Through underlying software models such as distributed simulation, a learner can be immersed in a synthetic, constructivist environment. The student acts and collaborates not as himself or herself, but behind the mask of an "avatar": a surrogate persona in the virtual world. Distributed simulation is a powerful educational delivery mechanism developed by the U.S. Department of Defense in the late 1980s. This instructional approach enhances students' ability to apply abstract knowledge by situating education in authentic, virtual contexts similar to the environments in which learners' skills will be used (Dede, 1992).

As one illustration, SimNet (Orlansky & Thorp, 1991) is a training application that creates a virtual battlefield on which learners at remote sites can develop collective military skills. The appearance and capabilities of graphically represented military equipment alter second-by-second as the virtual battle evolves. Complex data-objects that indicate changes in the state of the equipment are exchanged via a telephone network interconnecting the training workstations ("dial-a-war"). In the next generation of battle training simulations, learners will individually maneuver their virtual selves through weapons systems and landscapes populated by the avatars of friends and foes.

Via this type of information infrastructure, learners' collaborative interactions in synthetic constructivist environments can occur across distance, among avatars. In such virtual worlds, interpersonal dynamics provide leverage for learning activities in a manner rather different than typical face-to-face collaborative encounters. For example, participants in synthetic environments such as SimNet often feel as if the machine-based agents they encounter are real human beings, an illustration of the general principle that users tend to anthropomorphize information technologies. By using machine-based agents as synthetic personalities in a virtual corporate environment, the Advanced Learning Technologies Project at Carnegie Mellon University has taken advantage of anthropomorphization as a means to teach software engineering skills (Stevens, 1989). The agents provide both intellectual and psychosocial feedback to students, mimicking the types of interactions occurring in face-to-face constructivist learning (Dede, 1992).

As a complement to responding to knowbots as if they were human, participants in a virtual world interacting via avatars tend to treat each other as imaginary beings. An intriguing example of this phenomenon is documented in research on Lucasfilm's Habitat (Morningstar, & Farmer, 1991). Habitat was initially designed to be an on-line entertainment medium in which people could meet in a virtual environment to play adventure games. Users, however, extended the system into a full-fledged virtual community with a unique culture; rather than playing pre-scripted fantasy games, they focused on constructing new lifestyles and utopian societies.

As an entertainment-oriented cyberspace, Habitat provided participants the opportunity to get married or divorced (without real-world repercussions), start businesses (without risking money), found religions (without real-world persecution), murder others' avatars (without moral qualms), and tailor the appearance of one's own avatar to assume a range of personal identities (e.g. movie star, dragon, invisible sprite). Just as SimNet enables virtual battles, Habitat and its successors empower users to construct artificial cultures. What people want from these virtual societies that the real world cannot offer is magic, such as the gender-alteration machine (Change-o-matic) that was one of the most popular devices in the Habitat world.

As in all constructivist learning, centralized, top-down planning fails in Habitat-like environments, because users prefer to design their own culture and artifacts. For example, Fujitsu's Populopolis (Japan's version of Habitat) has incorporated characteristics typical of Japanese society. As one illustration, Populopolis users make extensive use in written textual communication of a sign language they invented to provide the nonverbal context—usually conveyed through gesture, posture, and tone of voice—so important in Japanese culture (Yoshida & Kakuta, 1993).

Users learned more about their innermost needs and desires by participating in Habitat than they would have by spending an equivalent amount of time listening to psychology lectures. Similarly, social scientists are discovering more about utopias by studying Habitat's successors than they did by researching communes, which were too restricted by real-world considerations to meaningfully mirror people's visions of ideal communities. Giving users magical powers opens up learning in ways that educators are just beginning to understand. As with any emerging medium, first traditional types of content (e.g. instructionist approaches) are ported to the new channel; then alternative, more constructivist forms of expression—like Habitat—are created to take advantage of expanded capabilities for communication and education.

Beyond Habitat-like synthetic environments, another new form of virtual expression is what Rheingold (1993) terms "real-time tribes," the cross-cultural melange of written conversations proliferating under the technological medium of Internet Relay Chat. Stable identities, quick wit, and the use of words to construct an imagined shared context for interchange are the hallmarks of this environment, which is less formally structured than adventure-based worlds. As examples such as Habitat and Internet Relay Chat illustrate, synthetic simulation environments center on interaction and collaboration—unlike the passive, observational behavior induced by television and presentational multimedia—and are therefore well suited for constructivist experiences.

Virtual Cultures as a Lever for Constructivist Learning

Existing virtual communities provide a testbed for understanding what types of design heuristics attract and sustain students' interest in synthetic worlds for constructivist learning. Focusing on what participants want is very important to designing any type of learning environment, so researchers are now beginning to study the personality characteristics of users who find virtual environments of value. One such population is people who don't do well in spontaneous spoken interaction (e.g. shy, reflective, more comfortable with emotional distance), but who have valuable contributions to share with others. For this type of person, informal written communication is often more authentic than face-to-face verbal exchange. This may be a whole new dimension of learning styles orthogonal to the visual/auditory/kinesthetic/symbolic categories now underlying pedagogical approaches to individualization.

In addition, a wide range of participants are attracted to cooperative virtual environments because they gain something valuable by collaborating together. Social network capital (an instant web of contacts with useful skills), knowledge capital (a personal, distributed brain trust with just-in-time answers to immediate questions), and communion (psychological/spiritual support from people who share common joys and trials) are three types of "collective goods" that bind together virtual communities enabled by computer-mediated communication (Smith, 1992). Similar types of inducements to collaboration underlie face-to-face constructivist learning experiences.

One illustration of how people's behavior shifts in virtual worlds is exemplified by the ongoing overlay of textual commentary that establishes social context in current synthetic environments, such as Habitat or Internet Relay Chat. Historically, the social context cues that guide communication have been more physical than verbal (e.g. modes of dress, tone of voice, posture). In a world stripped of non-verbal context, users playfully recreate this context through written descriptions of props for a virtual culture: plans, recipes, rules, instructions for the governing of behavior (Reid, 1991). Developing a rhetoric for interchanges among avatars in distributed constructivist environments is vital to their educational effectiveness.

Perhaps because a synthetic social context is less mutually apparent than co-habiting a physical environment—and therefore less subject to consensual agreement—users experience both positive and negative disinhibition. Normally shy people speak out more, but usually polite people also "flame" more at others, hurling insults on-line that they would never use face-to-face (Sproull & Kiesler, 1991). While negative behavior must be channeled into isolated contexts that minimize damage to others, disinhibition is a potential lever for learning in constructivist environments, since this creates cognitive and emotional dissonance that can undercut suboptimal mental models.

Another psychosocial dynamic of virtual environments that opens opportunities to encourage learning is the fluidity of users' identity. Prior communications media (the printed word, the telephone, the television) dissolved social boundaries related to time and space. Synthetic environments based on text and computer graphics dissolve boundaries of identity as well, enabling communication about very personal things through a depersonalized medium (Rheingold, 1993). Many aspects of this openness are quite positive from a constructivist perspective, as people often reject new ideas because they feel that their own identities are contained in their existing mental models. However, the challenging side of personal revelation is that an avatar's authenticity is always questionable due to the masking and distancing properties of the medium.

One type of virtual environment that illustrates these challenges and opportunities of authenticity is Multi-User Dungeons (MUDs). These are magical, text-based worlds where users can assume fluid, anonymous identities and vicariously experience intriguing situations cast in a dramatic format. Beyond words as a vehicle for meaning, poses are also used; someone can leap on-stage, smirk, or disappear in a puff of smoke. The continual evolution of the shared environment based on participants' collaborative interactions keeps MUDs from becoming boring and stale. In contrast to standard adventure games, where one wanders through someone else's fantasy, the ability to personalize an environment and receive recognition from others for a widely appreciated addition to the shared context is attractive to users (as is also true in face-to-face constructivist learning environments).

This psychosocial fascination is not always positive for participants. Some users find MUDs so compelling a medium that they fall into addictive behaviors (Bruckman, 1992). Being able to have interesting conversations with people on demand—any time of the day or night, with your own identify fluid—can induce communications addiction in a significant number of participants. Moreover, access to desirable high-level magical powers (such as the ability to modify the simulation environment) often requires developing a detailed mastery of a MUD's lore and the rules collectively developed by its inhabitants—a process that can be both time-consuming and largely uncorrelated with learning.

The key psychological component underlying this type of addictive behavior may be need for mastery, competence in controlling one's environment (Turkle, 1984). People who feel that their self-image is based on exerting perfect control over their surroundings may seek refuge in simplistic virtual environments that provide an escape from the complexities and uncertainties of the real world. This is the opposite of a constructivist situation, in which learners deliberately expose themselves to challenge and paradox in search of new insights into order and meaning. A thin line separates being a virtuoso in a medium from being a prisoner addicted to a communications vehicle; promoting the former rather than the latter is a major issue in designing synthetic constructivist environments.

Magical media incorporating avatars are very seductive in inducing a desire for mastery because mimesis—feeling as if what happens to another is happening to you—is an ancient, powerful emotion at the heart of all drama (Laurel, 1991). While this can lead to escapism, as a dramatist knows, with good design the focus of mimesis shifts to playful exploration, learning by doing, and catharsis—all important processes for inducing constructivist learning. MUDs are gradually transforming into MUSEs (Multi-User Simulation Environments), which focus on shared learning within the computer-based world. Constructing utopian visions to empower transforming everyday reality has been historically powerful as a change mechanism; MUSEs are a new vehicle for accomplishing this goal.

Constructivist learning activities in MUSEs may empower finding one's identity rather than losing it in escapism and masking. Goffman's seminal work, *Presentation of the Self in Everyday Life* (1959), asserts that people are always on-stage, creating a persona that they present to one audience or another. Some types of participants who are attracted to virtual communities (e.g. people denying unpleasant aspects of reality; people who present a persona to the world radically different than their internal self-image) are likely to have suboptimal learning behaviors as well. Synthetic constructivist environments provide a safe, anonymous opportunity to experiment with a new persona centered on a learning-centered lifestyle. For example, a person who feels ashamed of "being wrong"—and therefore is frightened of learning-by-doing situations—while masked within the context of a virtual community can safely risk making mistakes in the process of learning.

Evolving Mental Models Via Immersion in Artificial Realities

The key capabilities that distributed synthetic environments for learning add to current educational media are:

— telepresence via avatars (perceived simultaneous presence in a virtual environment by geographically separated learners), and

— immersion (the subjective impression that a user is participating in a "world" comprehensive and realistic enough to induce the willing suspension of disbelief).

The induction of immersion and telepresence depends in part on actional and symbolic factors.

Inducing actional immersion involves empowering the participant in a virtual environment to initiate actions that have novel, intriguing consequences. For example, when a baby is learning to walk, the degree of concentration this activity creates in the child is extraordinary. Discovering new capabilities to shape one's environment is highly motivating and sharply focuses attention.

Inducing a participant's symbolic immersion involves triggering powerful semantic associations via the content of a virtual environment. As an illustration, reading a horror novel at midnight in a strange house builds a mounting sense of terror, even though one's physical context is unchanging and rationally safe. Invoking intellectual, emotional, and normative archetypes deepens one's experience in a virtual environment by imposing an complex overlay of associative mental models.

Distributed synthetic environments offer tremendous potential for actional and symbolic immersion. In fact, moderate-bandwidth environments such as SimNet may leverage more learning and behavioral change than interactions within high-bandwidth media (e.g. real-time videolinks) or low-bandwidth communication (such as electronic mail). Reflective asynchronous interaction, the playful re-creation of social context, the opportunity to try on a new persona, and catharsis are powerful levers for learning that may be optimally realized via a moderate-bandwidth communications channel.

The vignette below illustrates the potential for learning-by-doing in a distributed, synthetic environment that relies on actional and symbolic immersion for motivation. This constructivist learning experience takes place in a student's home, about 10:30 in the evening:

Vignette: Navigating Through Cyberspace

Roger was unobtrusively sidling across the Bridge of the Starship Enterprise when the Captain spotted him out of the corner of his eye. "Take the helm, Ensign Pulver," growled Captain Jean-Luc Picard, "and pilot a course through the corona of that star at lightspeed 0.999. We have astrophysical samples to collect. You'll have to guard against strange relativistic effects at that speed, but our shields cannot stand the radiation flux we would experience traveling less quickly."

As Picard glared at him from the screen of his home ITV *(interactive-television set),* Roger drummed on his Cyberspace Console with his fingers and cursed quietly to himself. He had intended to sneak onto the Ecology Deck of the Starship and put in a little work on his biology class project in controlling closed-system pollution levels—but no such luck. Worse yet, Roger suspected that the Vulcan communications officer watching him while she translated a message in French was in fact the "avatar" *(computer-graphics representation of a person)* of a woman he admired who sat three rows behind him in his languages class. Of course, he could be wrong; she might be someone teleporting into this simulation from who knows where or could even be a "knowbot" *(a machine-based simulated personality used to simplify the job of the instructor Mage directing an constructivist simulation).*

Buying a little time by summoning up the flight log, Roger glanced curiously around the bridge to see what new artifacts his fellow students had added since yesterday to this MUSE. In one corner, an intriguing creature was sitting in a transparent box, breathing a bluish-green atmosphere—maybe this was the long-awaited alien the university's anthropology and biology majors were creating as a mutual project. The 3-D goggles from his Nintendo++ set intensified the illusion that the lizard-like countenance was staring right at him.

"Impulse Engines to full speed, Mister," barked Captain Picard! "This Mage seemed rather grumpy for a regular instructor," thought Roger, "maybe he's a visiting fireman from the new Net-the-Experts program." On his Console, Roger rapidly selected equations that he hoped would yield the appropriate relativistic corrections for successfully navigating through the star's corona.

Automatically, a cognitive audit trail of his actions began streaming to his factual-knowledge assessment file for physics. Each time he requested help from the computer-based coach, the performance score displayed on his Console dropped. "Why," said Roger sadly to himself, "couldn't I have lived in the days when students got to take multiple-choice tests..."

The potential interactions among avatars and virtual cultures in this hypothetical synthetic environment illustrate how shared evolution of physical/social context, fluidity of identity, disinhibition, and mimesis can empower distributed, constructivist learning.

Work in Progress: ScienceSpace

Beyond actional and symbolic immersion, advances in interface technology also enable physical immersion in artificial realities designed to enhance learning. Inducing an sense of physical immersion involves manipulating human sensory systems (especially the visual system) to enable the suspension of disbelief that one is surrounded by a virtual world. The impression is that of being inside an artificial reality rather than looking through a computer monitor "window" into a synthetic environment: the equivalent of diving rather than riding in a glass-bottomed boat.

A weak analog to physical immersion interfaces that many readers will have experienced is the IMAX motion picture theater, in which a two-story by three-story screen and high resolution images generate in the observer strong sensations of motion. Adding stereoscopic images, highly directional and realistic sound, tactile force-feedback, a visual field even wider than IMAX, and the ability to interact with the virtual world through natural physical actions produces a profound sensation of "being there," as opposed to watching. Because common sense responses to physical stimuli work in artificial realities, the learner quickly develops feelings of mastery, rather than the perception of helplessness and frustration typical when first attempting to use an unfamiliar computer interface or operating system.

With my colleague (R. Bowen Loftin at the University of Houston), my graduate students and I have recently begun the design of ScienceSpace, a series of artificial realities that explore the potential utility of physical immersion to enhance science education. One objective of this project is researching whether physically immersive constructivist learning can remediate typical misconceptions in the mental models of reality held by many students. Another is studying whether mastery of traditionally difficult subjects (e.g. relativity, quantum mechanics, molecular-orbital chemical bonding) is enhanced by physically immersive, collaborative learning-by-doing.

Most people's mental models include misconceptions that stem from misinterpreting common personal experiences with complex real-world phenomena, in which many forces are simultaneously acting. For example, the deceptively universal presence of friction makes objects in motion seem to slow and stop "on their own," undercutting belief in Newton's first law. As a result, most learners—including many science majors—have difficulty understanding physics concepts and models at the qualitative level, let alone the problems that occur with quantitative formulation (Reif & Larkin, 1992). These misconceptions, based on a lifetime of experience, are very difficult to remediate with instructionist pedagogical strategies.

We are studying whether physically immersive, shared artificial realities that allow users to alter the laws of nature can empower learners' constructivist evolution of mental models to correct pervasive misconceptions. Some of this work extends into physical immersion many ideas underlying 2-D constructivist microworlds for physics designed by researchers such as Barbara White (1993) and Andrea diSessa (Sherin, diSessa, & Hammer; 1993). Also, Sachter's research (1991) on how learners construct sophisticated mental models of 3-D space is providing valuable design heuristics for developing the interface to these immersive environments.

In incipient form, our ScienceSpace "worlds" for learning mechanics and dynamics in physics provide support for altering the magnitude and direction of gravitational acceleration, as well as the magnitudes of atmospheric drag, frictional coefficients between surfaces, and objects' coefficients of restitution. In addition, observations and measurements are made possible by controls that "freeze" the passage of time while objects are positioned and given initial velocities. Visualization, sonification, and tactilization features help learners sense attributes of objects in motion; and a display provides time, displacement, velocity, and acceleration data.

Of course, remediating misconceptions is not the only role that artificial realities designed for constructivist learning can play in science and technology education. Subjects such as quantum mechanics, relativity, and molecular bonding are difficult to teach in part because learners cannot draw analogies to personal experience that provides a metaphor for these phenomena. As a second objective for our research, we will construct immersive worlds that enable learners to experience near light-speed travel or quantum events, thus attempting to inculcate a instinctive, qualitative appreciation for these situations. This provides a phenomenological foundation for scientific principles that have been very difficult to teach.

Over the next two years, we will extend our early designs of ScienceSpace to a variety of phenomena from the physical, life, and earth sciences. Controlled trials will be conducted to assess the leverage for learning that different characteristics of these artificial realities provide. We plan to compare some types of learner outcomes in these artificial realities to similar outcomes using small-screen, two-dimensional simulations. These contrasts will help to clarify the relative utility of physical immersion and may suggest design principles for optimizing the educational value of artificial reality interfaces.

Through distributed simulation approaches, we can support shared interaction in a distributed virtual reality—even across merely moderate-bandwidth networks, such as the Internet—thus enabling telepresence and collaboration among learners' avatars. Designing the visual appearance of these avatars and what communications modes they can use to maximize constructivist learning is an intriguing challenge. Issues of mimesis, fluidity of identity, and disinhibition are among the important themes to consider. If synthetic environments for constructivist learning are not eerily beautiful, magical places that arouse curiosity and empower shared fantasy, we will lose our potential audience of students to the mindless videogame worlds of Sonic, the SuperMario Brothers, and the death patrols.

Conclusion

Alfred, Lord Tennyson's poem, "The Lady of Shalott," depicts the complexities of understanding the real world via vicariously experiencing its mirrored, magical reflections in a synthetic environment. His poem ends tragically; ultimately, its protagonist is unable to live either in the virtual or the real world. Nonetheless, fairyland continues to attract both children and adults as a magical alternate reality. With careful design, I believe that occasional immersion of the self in distributed simulations and virtual worlds can enhance learners' understanding of phenomena and culture in our shared physical/social reality.

Gelerntner (1992) is quite optimistic about how soon we will be able to utilize "mirror worlds" to understand and manipulate nature, artifacts, and society. However, creating distributed, constructivist learning environments is likely to be quite challenging, as avatars and immersion introduce new subtleties to the intercommunication that evolves shared cultural interpretations of reality. This article sketches the beginnings in a long journey of exploration on how to use the power of imagination wisely in creating collective universes that facilitate learning.

Despite these challenges, however, incorporating collaboratively evolved virtual worlds into many aspects of public education may empower more than mastery of material. As America's National Information Infrastructure evolves, Rheingold (1993) portrays a fundamental choice between a virtual forum that enables true democracy and open-ended learning ("Athens without slaves") or a pervasive surveillance medium for propaganda and escapism (virtual "bread and circuses"). Creating constructivist, collaborative educational experiences that encourage the former outcome is an important means for ensuring full public access to and control of this emerging meta-medium.

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