Emerging Technologies and Distributed Learning

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The development of high performance computing and communications is creating new media, such as the WorldWide Web and virtual realities. In turn, these new media enable new types of messages and experiences; for example, interpersonal interactions across network channels lead to the formation of virtual communities. The innovative kinds of pedagogy empowered by these emerging media, messages, and experiences make possible an evolution of synchronous, group, presentation-centered forms of distance education—which replicate traditional "teaching by telling" across barriers of distance and time—into an alternative instructional paradigm: distributed learning. In particular, advances in computer-supported collaborative learning, multimedia/hypermedia, and experiential simulation offer the potential to create shared "learning-through-doing environments" available anyplace, any time, on demand.

This article speculates about how emerging technologies may reshape both face-to-face and distance education. Its purpose is to delineate a three-part conceptual framework (knowledge webs, virtual communities, and shared synthetic environments) for understanding the new types of instructional messages that enable distributed learning. Although this study cites leading edge scholarship to reinforce its claims, it is a position/discussion piece rather than an inclusive review of all relevant distance education or educational technology research. As such, the emphasis is on expanding the reader's conceptualization of "distance education" rather than on proving the validity of specific pedagogical practices.

Because the technologies discussed are still swiftly evolving, case studies and formative evaluations are the predominant types of scholarship available. Moreover, both instructional technology and distance education lack extensive quantitative research on pedagogical strategies and designs. This potentially constrains the generalizability of the evaluative studies described and places the ideas presented in the realm of informed surmise rather than proven fact. However, these limitations are intrinsic in any attempt to depict the future of a field.

At a time when the technologies, economics, and public policies underlying all forms of schooling are rapidly shifting, distance educators cannot afford to wait until this evolving situation is fully understood and some standardized recipe for innovation can be constructed. By sketching emerging opportunities and assessing their potential implications, this position paper seeks to draw its readers into a dialogue on how the field of distance education should invent its future by rethinking its fundamental assumptions about teaching and learning.

Implications of New Media for Distance Education

What does the evolution of new media mean for distance educators? A medium is in part a channel for conveying content; new media such as the Internet mean that we can readily reach wider, more diverse audiences. Just as important, however, is that a medium is a representational container enabling new types of messages (e.g., sometimes a picture is worth a thousand words). Since the process of thinking is based on representations such as language and imagery, the process of learning is strongly shaped by the types of instructional messages we can exchange with students. Emerging representational containers, such as virtual reality, enable a broader, more powerful repertoire of pedagogical strategies.

The global marketplace and the communications and entertainment industries are driving the rapid evolution of high performance computing and communications. Regional, national, and global information infrastructures are developing that enhance our abilities to sense and act and learn across barriers of distance and time. How information is created, delivered, and used in business, government and society is swiftly changing. To successfully prepare students as workers and citizens, educators must incorporate into the curriculum experiences with creating and utilizing new forms of expression, such as multimedia (Dede & Lewis, 1995).

The "information superhighway" metaphor now widely used to convey the implications of high performance computing and communications is inadequate. Such an analogy is the equivalent of someone in 1896 declaring that the airplane will be the canal system of the 20th century. Backward looking metaphors focus on what we can automate—how we can use new channels to send conventional forms of content more efficiently—but miss the true innovation: redefining how we communicate and educate by using new types of messages and experiences to be more effective. Since emerging forms of representation such as hypermedia and virtual reality are in their early stages of development, we are just beginning to understand how they shape not only their messages, but also their users.

Many people are still reeling from the first impact of high performance computing and communications: shifting from the challenge of not getting enough information to the challenge of surviving too much information. The core skill for today's workplace is not foraging for data, but filtering a plethora of incoming information. The emerging literacy we all must master requires diving into a sea of information, immersing ourselves in data to harvest patterns of knowledge just as fish extract oxygen from water via their gills. As educators, understanding how to structure learning experiences to make such immersion possible is the core of the new rhetoric. Expanding traditional definitions of literacy and rhetoric into immersion-centered experiences of interacting with information is crucial to preparing students for full participation in 21st century society (Dede, 1992).

Synchronous, group, presentation-centered forms of distance education are similar to traditional classroom instruction. In contrast, emerging forms of distributed learning are based both on shifts in what learners need to be prepared for the future and on new capabilities in the pedagogical repertoire of teachers. "Learning-through-doing" involves participating in an individualized sequence of presentational and "constructivist" (guided learning-by-doing) experiences that are delivered on demand in a real world problem solving context. Three forms of expression are shaping the emergence of distributed learning-through-doing as a pedagogical model:

- knowledge webs complement teachers, texts, libraries, and archives as sources of information;
- interactions in virtual communities complement face-to-face relationships in classrooms; and
- immersive experiences in shared synthetic environments extend learning-by-doing in real world settings.

We are just beginning to understand how these representational containers can reshape the content, process, and delivery of presentation-centered distance education.

Information infrastructures are the lever for this evolution, just as the steam engine was the driver for the industrial revolution. The emerging fields of multimedia/hypermedia, computer-supported collaborative learning, and experiential simulation are creating the tools that make these new forms of expression possible. Knowledge webs are built on multimedia/hypermedia architectures; virtual communities are based on capabilities from computer-supported cooperative learning; and synthetic environments extend experiential simulation into elaborate contexts for immersion.

Learning-Through-Doing Via Multimedia and Hypermedia

Multimedia and hypermedia are learner-controlled interactive technologies; users can tailor presentations by selecting paths through the material customized to their interests. Also, these educational applications display data in multiple formats simultaneously (text, still images, animations, video, voices, sounds, music); this enables people with various learning styles (visual, auditory, symbolic) to initially peruse material presented in their preferred mode of communication. In addition, by displaying webs of interrelationships through concept maps or similar graphic devices, hypermedia systems enable learners to focus on the links among pieces of information, as well as the data itself.

A vital form of literacy for educators to communicate is how to transform archival information into personal knowledge. Moving students from access through assimilation to appropriation requires educational experiences that empower knowledge construction by unsophisticated learners, helping them make sense of massive, incomplete, and inconsistent information sources. Increasingly, leading-edge developers in multimedia/hypermedia are complementing presentational pedagogical approaches with constructivist, learning-through-doing instructional experiences, as the following examples illustrate.

Jasper Videodisc Series for Mathematics Learning

An exemplary illustration of moving beyond purely presentational multimedia/hypermedia to learning-through doing pedagogical approaches is the Jasper videodisc series for mathematics learning developed by the Cognition and Technology Group at Vanderbilt University (Cognition & Technology Group, 1992). "The Adventures of Jasper Woodbury" is a video-based series designed to promote problem solving, reasoning, and effective communication. After viewing each quarter-hour adventure, a complex challenge integral to resolving the adventure's narrative is presented to upper-level elementary students; these authentic problems are based on real world issues such as trip planning or generating a business plan using statistics. Over the course of a week, students must work together to solve these problems before they view how the movie characters resolve the same challenges. Using a videodisc with associated textual and graphic materials, learners first navigate through a complicated multimedia database to find the information they need to formulate the problem, then apply mathematical reasoning to solve the challenge and to generalize their solution to related problems presented in ancillary materials.

For example, in the adventure "Rescue at Boone's Meadow," the protagonists must convey a wounded bald eagle to medical attention as quickly as possible. Alternative trip plans are possible through various combinations of people, vehicles, and routes. The ultralight airplane available as one of the vehicles introduces additional complexities of payload, range, and landing requirements. The mathematical, problem solving, and reasoning skills needed to find the optimal outcome generalize to a wide class of workplace related challenges, as do the teamwork and communication skills students must use in small groups competing to find the best solution.

Sophisticated, large-scale evaluations of the Jasper series show statistically significant results in the following areas (Goldman, Pellegrino, and Bransford, 1994):

1. Students working with Jasper understand basic math concepts as well as control group students exclusively studying these concepts during an same equivalent time period, even though Jasper does not directly teach basic math.
2. Students in Jasper-based classrooms perform better on word problems and planning problems than learners in equivalent control groups.
3. Students learning via the Jasper series had more positive attitudes toward mathematics and problem solving than control group students; in addition, Jasper students had a better self-image of their abilities to master this material.

On a qualitative level, teachers and parents were generally very positive about how well children responded to Jasper, in contrast to the conventional mathematics curriculum.

Multimedia-based experiences such as Jasper build knowledge and skills that bridge abstract mathematical formalisms to practical applications of these concepts in problem-solving contexts similar to real-world situations. To study how well this pedagogical module generalizes to distance-based learning, the Vanderbilt group is now adding distributed resources to this system, as well as generalizing their "anchored instruction" model to more advanced content.

Broadcast News Project

A second example of learning-through-doing via multimedia is the Broadcast News project at Northwestern University's Institute for Learning Sciences (Kass, Dooley, and Luksa, 1994). Broadcast News is a research prototype that teaches social studies and journalism skills to high school students by allowing them to edit and anchor a TV News Show. An embedded hypermedia system presents a rough draft of a news story; the learner's job as an assistant producer is to edit the text and video associated with that draft, eliminate bias, correct factual errors, and fill in missing details. To accomplish these tasks, the student must navigate through a complex web of multimedia source materials (including film segments, text files, and reference works).

Lists of frequently-asked-questions relevant to the story and the task are provided; if the learner asks one of these questions as a plea for help, this triggers textual responses and video clips of advice from experts in history, the social sciences, and journalism. An artificial intelligence-based program evaluates the student's edited version and provides detailed feedback on whether the story is now "ready for prime-time." If so, the system enables the learner to act as a news anchor by provided a computer-controlled teleprompter; segueing to video feeds at predetermined times; and creating a videotape of the student's broadcast to compare to other learners' broadcasts, as well as to professional news presentations of the same event.

The goal-based scenario of working as an assistant producer supplies an organizing framework for students' exploration of this hypermedia database, and the opportunity to serve as news anchor provides motivation for creating a quality product. Comparable multimedia databases and goal-based scenarios could be created for a range of occupational roles that involve information filtering and formatting. The Institute for Learning Sciences at Northwestern University is now applying the goal-based scenario format to a variety of training applications, as well as incorporating distributed resources to facilitate distance education using this pedagogical strategy.

Underlying Learning Model for Constructivist Multimedia/Hypermedia

The generic model of pedagogy underlying these types of multimedia/hypermedia systems is analogical, case-based learning-by-doing. Students navigate through a complex database, trying various strategies to reach an assigned goal. When their approaches fail because the mental model they have constructed of the task is inadequate, learners can request help through following links or triggering answers to prestructured questions. Both the materials students access and the processes they utilize to acquire information reflect concepts and skills valuable in workplace settings.

This type of case-based reasoning can generalize to a wide range of instructional applications. For example, the vignette below illustrates how a variant of this pedagogical strategy might be implemented in an on-line help system capable of delivering assistance on demand (Dede & Lewis, 1995). This scenario shows an apprentice physical therapist learning how to find his first job. Hypermedia, geographic information systems, and artificial intelligence are among the emerging technologies underlying this hypothetical system.

An apprentice physical therapist is learning how to identify prospective employers, then market himself effectively to them. He hums quietly to himself as he and his web terminal skim through a sea of stories, harvesting metaphors and analogies. By sifting through the stored experiences of students similar to him, he can identify new ideas to try, building on what others in comparable situations have already learned about finding a job.

On the computer monitor, a map of various hospitals and nursing homes in the city is shown, with some highlighted in different colors. Several paragraphs of text describing the current story are displayed at the bottom of the screen, ignored by the apprentice. Since his learning style is predominantly visual and auditory rather than symbolic, STORYWEB is vocalizing this textual material while he watches a graphical pointer maneuver about the diagram. At any point, he can interrupt the flow of this story to activate one of the hypermedia links at the left of the screen; these lead to related reference materials such as job application forms, material about unions, people to call for additional information, etc.

Three figurines are gesturing near the top of the display, indicating that they know related stories. The learner can leave this story at any time to shift into one of these related cases; if he does so, other figurines will appear, denoting the availability of additional stories related to this new case. In this manner, the user can traverse a web of interrelated cases to find those that are the best match for his interests and needs. In addition, the person who told each story can be accessed through the system via automated electronic mail, surface mail, or telephone messaging.

STORYWEB is a case-based reasoning shell that acts as a guide, conversing with a person engaged in problem solving and responding to problem descriptions with recollections about similar situations encountered by other practitioners. These concrete examples are pedagogically valuable in suggesting possible approaches, warning of potential pitfalls, and fleshing out abstract rules-of-thumb. Beyond a repertoire of stored cases, STORYWEB also provides access to other knowledge sources, including the people who told these stories.

Many of the technological capabilities in this vignette are based on extensions of current work. For example, Kolodner’s research on instructional applications of case-based reasoning inspired the vignette’s pedagogical strategy, and STORYWEB is loosely based on a prototype application she and her colleagues developed for learning about architecture (Domeshek & Kolodner, 1992). The network of stories depicted in the scenario has similarities to the TRANSASK story web developed at Northwestern University’s Institute for the Learning Sciences (Ferguson et al., 1991) Apple Computer’s work on “guides” embedded in multimedia applications to provide alternative perspectives provided the idea of the figurines at the top of the display (Laurel, Oren, & Don, 1990)

Scaling up Multimedia/Hypermedia into Knowledge Webs

As the vignette above suggests, "knowledge webs" enable distributed access to experts, archival resources, authentic environments, and shared investigations. We are accustomed to asking a well-informed person in our immediate vicinity for guidance, to consulting printed information or watching a news program, to visiting exhibits (such as a zoo) to learn about different types of environments, and to conducting informal experiments to understand how reality works. Often, these information gathering and creation activities are constrained by barriers of distance, restricted access, scheduling difficulties, and the limits of one's personal expertise in investigation.

On the Internet, on-line archival resources are increasingly linked into the WorldWide Web, accessible through “webcrawlers” such as Mosaic™ and Netscape™. Eventually, artificial intelligence-based guides will facilitate navigating through huge amounts of stored information. In time, these informal sources of expertise will utilize embedded “groupware” tools to enhance collaboration. Via information infrastructures, educators and students will join distributed conferences that provide an instant network of contacts with useful skills, a personal brain trust with just-in-time answers to immediate questions.

Virtual exhibits that duplicate real-world settings (e.g., museums) are emerging; these environments make possible a wide variety of experiences without the necessity of travel or scheduling. Distributed science projects enable conducting shared experiments dispersed across time and space, each team member learning more than would be possible in isolation about the phenomenon being studied and about scientific investigation. Combined, all these capabilities to enhance information gathering and creation form knowledge webs.

In developing these instructional resources, incorporating learning-through-doing and case-based pedagogical approaches aids in transcending a major weakness of presentational multimedia/hypermedia. Learning environments limited to information access are passive; the learner selects what to view and whether to seek help. While this type of student control may be motivating for many students, naive learners can waste substantial time aimlessly browsing, utilizing relatively unproductive strategies to attain the desired goal, or ignoring help from the system that could aid their progress. Designing implicit structure into the task, the web of links, and the opportunities for help is crucial in guiding effective learning with multimedia/hypermedia applications.

In addition, giving learners constructivist experiences with applying the ideas they have assimilated is important in facilitating their full comprehension, long-term retention, and ability to generalize instructional material. Access to data does not automatically expand students' knowledge; the availability of information does not intrinsically create an internal framework of ideas that learners can use to interpret reality. While presentational approaches transmit material rapidly from source to student, often this content evaporates quickly from learners' minds. To be motivated to master concepts and skills, students need to see the connection of what they are learning to the rest of their lives and to the mental models they already use. Even when learners are drilled in a topic until facts are indefinitely retained—we all know that the sum of a triangle's internal angles is 180 degrees—this knowledge is often "inert"; most people don't know how to apply the abstract principles they memorized in school to solving real-world problems.

To move students beyond assimilating inert facts into generating better mental models, teachers must structure learning experiences that highlight how new ideas can provide insights in intriguing, challenging situations. The curriculum is already overcrowded with low-level information; teachers frantically race through required material, helping students memorize factual data to be regurgitated on mandated, standardized tests. Using information infrastructures as a fire hose to spray yet more information into educational settings would make this situation even worse. Without skilled facilitation, many learners who access current knowledge webs will flounder in a morass of unstructured data. Weaving learner-centered, constructivist usage of linked, on-line materials into the curriculum and culture of traditional educational institutions is a next stage of evolution for presentational forms of distance education. As the examples above suggest, making these learning experiences a team effort via various types of collaboration can aid this process.

Computer-supported Collaborative Learning

Computer-supported collaborative learning (CSCL) enhances team performance through tools for communicating each person’s ideas, structuring group dialogue and decision making, recording the rationales for choices, and facilitating collective activities. With the teacher’s guidance, learners utilize these “groupware” tools to develop a shared mental model or to perform work-related tasks. Through advances in the bandwidth of our information infrastructures, CSCL is increasingly capable of supporting affective interactions and the formation of virtual communities. Such “telepresence” enables mentoring across distance and provides a social context that reinforces and motivates learning, as well as preparing students for telecommuting roles in the business environment.

Collaborative Visualization project (CoVis)

An exemplary illustration of computer-supported collaborative learning is the Collaborative Visualization project (CoVis) at Northwestern University’s Institute for Learning Sciences (Pea, 1993). To study the weather, high school students are using groupware tools to communicate across distance with other students, university researchers, and field-based scientific experts. The emphasis of this project is on atmospheric and environmental sciences—including meteorology and climatology—learned through shared scientific exploration and the use of visualization techniques similar to those employed by professionals.

The "collaboratory" workbench students utilize includes desktop video teleconferencing; joint software environments for remote, real-time collaboration; access to the Internet; a multimedia notebook with embedded templates for sharing ideas; and scientific visualization software. Through these media, learners determine authentic problems they would like to study (e.g., why is sand different in various locations?), identify people who can help them across distance, then use joint inquiry and shared design techniques to evolve answers to these problems. This provides both content knowledge potentially valuable in a range of occupations and generic process skills in inquiry and collaboration useful in any geographically distributed organizational setting.

Distant Mentor Project

A second leading-edge example of computer-supported collaborative learning is the Distant Mentor project at SRI International (Means, Schlager, and Poirier, 1994). Based on both a literature review and classroom field studies of the challenges in transposing skills from school to work, these researchers developed a conceptual framework, "cognitive mentoring," for enabling workplace experts to mentor students in an apprenticeship-across-distance mode. In this "telementoring" strategy, mentors and learners pass through six stages: initiative, negotiation, diagnosis, execution, evaluation, and reflection. This model was validated through field studies of on-the-job learning, and prototype CSCL tools were developed to support student and mentor in each stage of their interaction across distance.

"Distant mentoring" prototype software has been constructed for training students in skills associated with the operation of a circuit board manufacturing line. This application allows people in two different locations on a UNIX network to interact with a manufacturing simulation (and, potentially, many other types of work-related models), while maintaining a conversation over a network-based audio channel. Small-scale laboratory experiments have validated that the graphical user interface and natural language input associated with this collaboration shell are easy to master.

Teaching Teleapprenticeships

Another project that enhances trainees' skills through computer-supported collaborative learning links with distant workplace experts is the "Teaching Teleapprenticeships" work at the University of Illinois, Champaign-Urbana (Levin et al, 1994). This group is exploring several different types of teleapprenticeships for bachelor's level teacher education students; these involve interactions with Internet-based resources, apprenticeships with practicing teachers, and mentoring K-12 apprentices from participating classrooms. A Learning Research Server with a suite of specialized CSCL tools has been developed to facilitate these diverse kinds of teleapprenticeships. These CSCL tools include email and computer conferencing facilities, as well as a shared, structured knowledge space for collaborative access to educational materials (e.g., documents, images, software, sounds, databases). Through providing virtual collaboration facilities that allow workplace practitioners to aid in the preparation of students planning to assume similar jobs, the capabilities and pedagogical strategies that this project is evolving potentially generalize to a wide range of occupational preparation programs, .

The researchers are conducting teleapprenticeship field studies using this computer-supported collaborative learning environment to ascertain which tools are most useful and how they could be improved. These studies include teleapprenticeships for elementary education students in an introductory biology class, in a science methods course, and in a pre-service student teaching program; secondary teachers-in-training participated in teleapprenticeships in an English student teaching situation. Preliminary results indicate that the students found the collaboration tools valuable in overcoming barriers of time and distance that impede learning outside the classroom setting. Increased access to workplace experts (practicing teachers) was also cited as a major advantage.

Classrooms with Electronic Walls

Research on “classrooms with electronic walls” that can be superimposed on real-world settings is another example of leading-edge CSCL. By using notebook-sized computers, pen-based interfaces, wireless networking, and customized software, teachers can conduct field-based experiences in which students are physically distributed across an environment, yet linked together by shared data, collaborative discussion, and pedagogical guidance. In classrooms with electronic walls, the notebook computer carried by each student group accepts pen-based data input and continuously updates the information collected by all groups. Results are displayed on multimedia databases, spreadsheets, and geographic information systems customized to that lesson’s structure and are simultaneously available to all participants.

Walkie-talkies allow communication among groups separated by distance. Camcorders and digital cameras enable collecting visual data for documentation and analysis. A cellular phone and fax link the field-based team to both instructional resources and learners at a variety of sites. All this empowers collaborative groups of learners to collect data about authentic phenomena with guidance from a virtual community of peers, teachers, and subject experts. In the last several years, Apple Computer has conducted small-scale field trials that demonstrate the technical feasibility of this distributed learning approach (Cooper et al., 1994).

The capability to create these superimposable “classrooms with electronic walls” could be very useful in certain types of training. As illustrations:

- Students in an economics class could gather consumer behavior data in different sections of a shopping mall.

- Newly hired employees evaluating health care delivery could disperse throughout a hospital to monitor simultaneously the progression of a patient and his paperwork, while tracking doctors, nurses, and others involved in treatment.
- Trainees studying technology could master descriptive modeling techniques while studying the interacting engineering infrastructure subsystems of a typical community (e.g. power plants, highways).
- Urban planning students could extend systematically in different directions to produce computer maps documenting zoning, traffic flows, concentrations of various types of businesses, pollution levels, soil types, cultural patterns within neighborhoods.
- Trainees studying ecology could spread through a canyon, simultaneously relaying data to each other on changes in different habitats with the passage of time.

In addition, through this pedagogical approach, students learning any field can acquire overarching skills in inquiry, research methodology, statistics, and mathematical analysis. Further, they can engage experts in real-time discussions of authentic phenomena.

Underlying Learning Model for CSCL

Computer-supported collaborative learning is motivating for many students who would otherwise be uninterested in educational experiences delivered by instructional technology. 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).

CSCL systems are evolving from the “talking heads” format characteristic of unsophisticated distance education to suites of media and tools customized to different types of learning tasks. Also, through watching virtual communities in action, CSCL researchers are beginning to identify new dimensions of learning styles orthogonal to the visual/auditory/kinesthetic/symbolic categories now underlying pedagogical approaches to individualization. For example, some types of trainees who don’t do well in spontaneous spoken interaction (e.g., students who are shy, reflective, more comfortable with emotional distance) find that asynchronous, text-based communication better fits their learning style. For this kind of person, informal written communication via computer conferencing is often more “authentic” than face-to-face verbal exchange; lower bandwidth, cheaper groupware tools may work better for such students than high-end videoconferencing applications.

Creating a sense of communion among a distributed group linked by low to moderate bandwidth networking is a complex challenge (Dede, 1995). Some people favor technology-mediated communication as their most authentic way of sharing ideas and enjoying fellowship. Most people prefer face-to-face interaction, but find the convenience of just-in-time, anyplace access to others often outweighs the disadvantages of distributed sharing of ideas, experiences, and support. Groupware tools, a capable moderator, and shared interactivity and control are important for sustaining the vitality of virtual communities, as is occasional direct contact among participants.

As a means of illustrating how these CSCL strategies could enhance distributed learning, the vignette below portrays a teacher's aide-in-training mastering knowledge and skills via a mixture of technology resources distributed among a classroom setting, her home, and her future workplace. The technologies underlying this vignette include computer-based training via videodiscs and CD-ROMs, electronic mail and computer conferencing, and navigating tools for the World-Wide Web.

Gwen is a elementary school aide-in-training. She longs to be a teacher's aide, but had been reluctant to get her credentials until she heard about an innovative program at New Community College that integrates content, methods, and technology. She is now taking the elementary science methods workshop that has recently been reformulated to integrate materials from "The Idea of Science " project. She will use a core text; video programs that help illustrate important concepts; a workbook that helps her apply the concepts to different grade levels; a CD-ROM curriculum matrix that lists elementary school materials that relate to specific concepts; and on-line networks that allow her to contact peers, veteran science teachers, research scientists, and students representative of those she might teach. Gwen is just completing a lesson that she will teach tomorrow in Ms. Dean's third grade class. Ms. Dean has been teaching at a local elementary school for more than 12 years and is one of the many resource teachers who helps regularly with students in Dr. Farah's elementary science methods workshop at New Community College. For two weeks, Gwen and her peers have been planning a unit on ecosystems to enrich this third grade class's science instruction.

Gwen signed off the Science Methods Computer Conference Center (SMCCC), a local computer bulletin board and conferencing system operated by New Community College. She sighed: sixteen messages were a lot to wade through. Still, compared to the complexities of arranging face-to-face meetings or playing telephone tag, this method of interaction was a lot more effective. Developing shared goals and integrating their individual lessons had been relatively easy for her group. Communicating electronically was convenient; and their face-to-face planning meetings with Dr. Farah, guided by her text's workbook activity sheets, had soothed over a few potentially divisive conflicts.

The World-Wide Web had also proven a valuable resource for locating databases on ecology, as well as archives of third grade lesson plans and ongoing electronic forums on teaching science. "Surfing the net" had proven to be less difficult that Gwen had expected, in part because the concept map organizers on each resource's Home Page had provided a constant visual referent for aiding her navigation. The multimedia "pages" that displayed information in graphics, text, and images were particularly useful in suggesting ways to package content for the diverse learning styles of her students.

The video on ecosystems on the videodisc packaged with her textbook was certainly a rich resource. Even two weeks after viewing and discussing the video, she and her collaborators were still generating insights from it on how to teach the lesson tomorrow. Tonight, to evolve these ideas farther, Gwen planned to skim one more time through the ecosystems chapter in her text. Since her learning style was symbolic, she liked having textual material that complemented the video. Her insights on the readings had won respect from the visual learners in her group, improving Gwen's self-image. She no longer felt like a "drop- out."

Gwen finished printing her latest Internet message from Dr. Xao, a noted biochemist doing ground-breaking work on urban ecosystems. He had been delighted to help her group formulate the lesson and had suggested some engaging activities with ants to try with the third graders. Gwen had generally negative feelings about ants, but the lesson planning process had made her a little more appreciative of their role in the general scheme of things. She had to laugh at the "Good luck; break a leg!" salutation on his message. Scientists seemed much more approachable and human in this virtual community of electronic mail.

However, Gwen was glad that their workbook activities from the text had aided them in planning appropriate activities. The CD-ROM Curriculum Finder included with the textbook had been a big help as well in identifying materials both related to ecosystems and appropriate for grade three. If her group hadn't prepared a good plan for the lesson before contacting Dr. Xao, he might not have been so willing to assist.

Gwen also appreciated the encouraging Internet message she just received from Ms. Dean. She had remembered her own first night jitters and gave Gwen some suggestions on how to relax. Ms. Dean had participated in the group's planning and helped them to develop "practice lessons" blending into the total curriculum for her third grade class. Without computer conferencing and email, Gwen thought, Ms. Dean, Dr. Farah, and Dr. Xao would all have played a much smaller role as resources. For that matter, Ms. Dean would not have been able to consult other third grade teachers around the country who had used the curriculum materials that Gwen's group was considering. The several critiques Ms. Dean had received on the materials the group was considering had been invaluable for Gwen's planning.

The best message, though, had been from Dr. Farah, complimenting the group on its choice of evaluation strategies. Gwen felt proud, as she knew her own ideas were the core of that part of the unit. "Now I'm an expert on ants," she thought, "if I ever get bored with teaching, I can become an exterminator!" Relaxed and happy, Gwen shut off her personal computer and headed for the dining room; her husband had just finished cooking dinner.

With minor modifications, such multimedia applications for exploring webs of knowledge can present a variety of topics across the full spectrum of the pre-college curriculum (Fontana, Dede, White, & Cates, 1993). The richness of this expository medium helps to build learner motivation, an important issue for required subjects like science in which many students may initially be uninterested or phobic. With the guidance of the teacher, who remains at the center of the educational experience, learners progress from assimilating exemplary mental models to constructing their own interpretations of the concepts and principles underlying the material. Working in collaborative teams allows students to combine complementary backgrounds and learning styles, as well as developing psychosocial and communication skills.

Scaling up CSCL to Virtual Communities

Virtual communities that provide support from people who share common joys and trials are a powerful means of enhancing distributed learning. We are accustomed to face-to-face interaction as a means of getting to know people, sharing ideas and experiences, enjoying others' humor and fellowship, and finding solace. In a different manner, distributed learning via information infrastructures can satisfy these needs at any time, any place. Distance educators need the virtual communities information infrastructures make possible. Learning is social as well as intellectual. Individual, isolated attempts to make sense of complex data can easily fail unless the learner is encouraged by some larger group that is constructing shared knowledge. In addition, institutional evolution is a communal enterprise; educational innovators need emotional and intellectual support from others who have similar challenges in their lives.

Moreover, no matter how well schooling is done, achieving major gains in learning requires that the time students spend outside the classroom be educationally fulfilling as well. This necessitates close cooperation and shared responsibility for distributed learning among society's educational agents (families, social service agencies, workplaces, mass media, schools, higher education), which virtual communities can enhance. For example, involving families more deeply in their children's education may be the single most powerful lever for improved learning outcomes. Virtual parent-teacher conferences and less formal social interchanges make such involvement more likely for parents who will never come to a PTA meeting or a school-based event. In many regions across the U.S., community networks are emerging that, among other missions, enhance education by enabling distributed discourse among all the stakeholders in quality schooling.

Another illustration of a distributed learning use for virtual communities is peer tutoring. This instructional approach aids all students involved both intellectually and emotionally, but is difficult to implement in traditional classroom settings. Outside of school, virtual interactions enhanced by groupware tools readily enable such student-student relationships, as well as preparing their participants for later use of distributed problem solving techniques in adult workplace settings. Telementoring and teleapprenticeships between students and workplace experts are similar examples of applying virtual community capabilities to distributed learning. Through their expertise in encouraging interactivity across disparate geographic locations, distance educators have important insights to contribute in the evolution of virtual communities.

To succeed, distributed learning must balance virtual and direct interaction in sustaining communion among people. A relationship based only on telephone conversation lacks the vibrancy that face-to-face interchange provides. Similarly, while digital video will broaden the bandwidth of virtual interactions on information infrastructures, teleconferencing will never completely substitute for direct personal contact. We can expect a variety of social inventions to emerge that provide the best of both worlds and that incorporate CSCL tools into other types of educational applications, such as multimedia/hypermedia and experiential simulation.

Experiential Simulations

Experiential simulations range from models that mirror the simplified essence of reality to elaborate synthetic environments with immersion interfaces that place students inside alternate virtual worlds. Simulations can provide a learning experience for a single student or can involve multiple students interacting in a distributed virtual environment. Their content can reflect real phenomena made less complex to enhance understanding or can embody virtual universes that operate on different physical and social principles than our world.

Educators have long used simulations as a teaching tool; now, distributed simulation is emerging as an extension of this pedagogical strategy. Just as single-user simulations allow an individual to interact with a model of reality (e.g., flying a virtual airplane), distributed simulations enable many people at different locations to inhabit and shape a common synthetic environment. For example, the U.S. Department of Defense uses distributed simulation technology to create virtual battlefields on which learners at remote sites develop collective military skills (Orlansky & Thorp, 1991). The appearance and capabilities of graphically represented military equipment alter second-by-second as the virtual battle evolves ("dial-a-war"). This emerging representational container could be used to enhance the sophisticated types of instructional applications described below.

Virtual Corporate Setting

One exemplary illustration of experiential simulation applied to learning business-based skills involves software engineering education; students are trained in a technical process, code inspection, that is one stage of a formal methodology for software development (Stevens, 1989). Using hypermedia, Digital Video Interactive (DVI), and rule-based expert systems, the Advanced Learning Technologies Project at Carnegie Mellon University created a virtual environment similar to a typical corporate setting. The trainee interacts with this artificial reality in the role of a just-hired software engineer still learning the profession. Through direct instruction and simulated experience, the student practices the process of formal code inspection.

The learner can access various rooms in the virtual software company, including an auditorium, library, office, training center, and conference facility. Machine-based agents (knowbots) that simulate people, such as a trainer and a librarian, facilitate the use of resources to learn about the code inspection process. Via specialized tools in the office, the student can prepare for a simulated code inspection, in which he or she can choose to play any of three roles out of the four roles possible in this formal software review process. For each inspection, a rule-based expert system utilizes DVI technology to construct “knowbots” that simulate the three roles not chosen by the learner. This knowledge-based system controls the topic of conversation; determines who should speak next; and models the personalities of the knowbots in the inspection meeting, altering their cognitive and affective perspective depending on what is happening.

The learner uses a menu-based natural language interface to interact with these simulated beings, who model behaviors typical in code inspection situations. The student not only can choose from a wide range of options of what to say, but can determine when to make remarks and can select the emotional inflection of his or her utterances, from a calm passive tone to an aggressive snarl. By mimicking the reactions likely from human participants in a real simulation, the knowbots provide the learner with a sense of the strengths and weaknesses of different intellectual/psychosocial strategies for that role in a code inspection.

While the application built by this project focused on code inspection as the skill to be trained, through similar means preparation could be provided for a wide variety of work-related situations that involve social interaction within a limited range of formalized behaviors (e.g., learning to be a customs agent, developing skills in job interviewing). The educational effectiveness of this application was assessed both by the Southwest Research Institute and via a doctoral thesis at Carnegie Mellon University (Christel, 1994). The results of these evaluations document that this simulation is both instructionally effective and highly motivating for participants. While this Code Inspection simulation is created for a single user, a similar design strategy could be used to create a distributed simulation in which multiple users separated by distance could cohabit a virtual environment along with machine-based entities.

ScienceSpace Virtual Realities

A second example of leading-edge work with experiential simulation is ScienceSpace, an evolving suite of virtual worlds designed by the author and colleagues to aid students in mastering difficult science concepts (Salzman, Dede, & Loftin, 1995). Virtual reality is analogous to diving rather than looking through an aquarium window; an immersion interface based on computerized clothing and a head-mounted display allows the participant to feel “inside” an artificial world. Using this type of sensory immersion to present abstract, symbolic data in tangible form is a powerful means of attaining insights into real world phenomena. For example, “visualization” is an emerging type of rhetoric that enhances learning by using the human visual system to find patterns in large amounts of information. People have very powerful pattern recognition capabilities for images; much of our brain is "wetware" dedicated to this purpose. As a result, when tabular data of numerical variables such as temperature, pressure, and velocity are transfigured into graphical objects whose shifts in shape, texture, size, color, and motion convey the changing values of each variable, increased insights are often attained. For example, graphical data visualizations that model thunderstorm-related phenomena (e.g., downbursts, air flows, cloud movements) are valuable in helping meteorologists and students understand the dynamics of these weather systems.

As information infrastructures increasingly enable people to access large databases across distance, visualization tools can expand human perceptions so that we recognize underlying relationships that would otherwise be swamped in a sea of numbers. One good way to enhance creativity is to make the familiar strange and the strange, familiar; adding sonification and even tactile sensations to visual imagery can make abstract things tangible and vice versa. For example, expanding human perceptions (e.g. allowing a medical student—like Superman—to see the human body through X-ray vision) is a powerful method for deepening learners' motivation and their intuitions about physical phenomena.

ScienceSpace now consists of three virtual worlds in various states of maturity: NewtonWorld provides an environment for investigating the kinematics and dynamics of one-dimensional motion. MaxwellWorld supports the exploration of electrostatics, leading up to the concept of Gauss' Law. PaulingWorld enables the study of molecular structures via a variety of representations. These immersive synthetic environments complement existing approaches to science instruction through enabling learners' knowledge construction via 3-D representations; multiple perspectives/frames of reference; a multimodal interface; simultaneous visual, auditory, and haptic feedback; and types of interaction unavailable in the real world (e.g., seeing through objects, flying like Superman).

By themselves becoming part of a phenomenon (e.g., a student becomes a point mass, undergoing collisions in a frictionless artificial reality), learners gain direct experiential intuitions about how the natural world operates. Transducing data and abstract concepts (e.g., acceleration) into multisensory representations is also a powerful means of enhancing understanding. With careful design, these capabilities all can synthesize to create a profound sense of motivation and concentration conducive to mastering complex, abstract material. Under these conditions, learners may be able to construct mental models of phenomena that have no counterpart in their everyday experience (e.g., relativity, quantum mechanics).

An overarching theme in this ScienceSpace research is to develop a theory of how multisensory “immersion” aids learning. In all our worlds, we are experimenting with collaborative learning among geographically remote users inhabiting a shared virtual context. Cooperation among users’ “avatars” in shared synthetic environments enables a wider range of pedagogical strategies (e.g., peer teaching, tutoring, apprenticeship) and may make VR environments more intriguing to students who are most motivated to learn when intellectual content is contextualized in a social setting. Via a dedicated ISDN telephone line, we can implement shared worlds through links between Texas and Virginia, using technology similar to that developed by NASA to train astronauts in Houston and Germany to train in the same virtual environment.

We are currently extending this virtual reality research in science education to exploring a different issue: whether intercultural communication can be taught in synthetic environments. The challenge is rapidly training military personnel for peacekeeping and disaster relief operations. In these situations, correctly interpreting and emoting nonverbal, interpersonal signals unique to that cultural setting is crucial. If successful, studies of affective communication in shared, distributed synthetic environments could generalize to a wide range of educational contexts.

Remote Exploratoriums

A third group using experiential simulation to enhance distributed learning is Fischer's Center for Lifelong Learning and Design at the University of Colorado, Boulder. Their "Remote Exploratoriums" project is designed to move students navigating the World-Wide Web beyond the passive role of viewing archives to the active role of manipulating simulations and models (Repenning & Sumner, 1995). The network-accessible exploratory design environments being constructed enable students to build artifacts; work-related learning environments already developed include a simulation world for electric circuits, a model of melting ice, and a virtual ocean ecology.

The authoring application for these remote exploratoria is Agentsheets, a visual programming environment based on a grid system roughly parallel to spreadsheets and cellular automata. Agentsheets has been integrated into the World-Wide Web to enable remote access and interaction. This work on distributed simulation environments is in an early prototyping stage, but research conducted on non-remote simulations constructed with Agentsheets indicates that students are motivated and engage in virtual design activities similar to those used by professionals in workplace settings.

Underlying Learning Model for Experiential Simulation

As with constructivist multimedia/hypermedia, the generic model of learning underlying most types of experiential simulation systems is analogical, case-based construction of knowledge. Students try an approach; if it fails, they reflect on why, then "replay" using another strategy. This type of instruction works best for students who already have some background knowledge and wish to practice their skills. Naive learners just beginning to understand a subject often flounder in virtual learning-by-doing environments, leading to frustration. Students who need a lot of structure and guidance also tend to find experiential simulation confusing.

In virtual worlds, interpersonal dynamics provide leverage for learning activities in a manner rather different than typical face-to-face encounters. For example, participants in synthetic environments 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 (Weitzenbaum, 1976). 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.

Perhaps because a synthetic social context is less mutually apparent than cohabiting a physical environment—and therefore less subject to consensual agreement—users often experience both positive and negative disinhibition. Normally shy people speak out more, but usually polite people also “flame” more at others, hurling insults 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. In the early stages of instruction, disinhibition is also valuable in encouraging learners to ask “dumb questions” of experts without feeling shy about showing ignorance.

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. The psychosocial fascination that experiential simulation induces is not always positive for participants. Some users find virtual worlds 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 some participants. Turkle (1984) has studied which types of personalities may be most vulnerable to this form of addiction. This issue is important in the design of simulated environments for workplace training in order to ensure that learners stay on-task without being unduly distracted by social aspects of the virtual world. With careful psychosocial design, however, distributed experiential simulations linked to knowledge webs and CSCL tools are a powerful medium for just-in-time, anyplace learning.

Shared Synthetic Environments that Complement Real World Experiences

Shared synthetic environments can extend our experiences beyond what we can encounter in the real world. Information infrastructures are not only channels for transmitting content, but also communal virtual worlds that students can enter and explore. As an example, the vignette below depicts a hypothetical future application that promotes distributed learning outside the classroom through “edutainment.”

EDUTAINMENT IN 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 through traveling less quickly.” Roger 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, he 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 instructors directing an instructional 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 MUD *(Multi-User-Dungeon or Dimension, a current type of adventure game in which participants mutually evolve an elaborate, shared synthetic environment by continuously modifying its contents).* 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 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 *(human expert guiding the evolution of a virtual environment)* seems rather grumpy for a regular teacher,” 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. He hoped to impress Captain Picard as a means of improving his chances for promotion. Last week’s setback, getting motion sick while “riding” on a virtual gas molecule that was illustrating Brownian motion, had not helped his chances...

This vignette shows how education could be situated in a synthetic universe analogous to a authentic real-world environment, but more intriguing. Moreover, such a distributed learning strategy leverages a huge installed base of sophisticated information technology—home videogame consoles—as well as the substantial motivation inculcated by the entertainment industry.

Even without the added enhancement of visual imagery, the rise on the Internet of text-based shared synthetic environments (e.g., MUDs, MUSEs, MOOs) illustrates people’s fascination with participatory virtual worlds. The continual evolution of distributed simulations based on participants' collaborative interactions keeps these shared virtual environments from becoming boring and stale. In contrast to standard adventure games, in which you wander through someone else's fantasy, the ability to personalize an environment and receive recognition from others for adding to the shared context is attractive to many people. Part of why we read fiction or watch dramatic productions is to escape the ordinary in a manner that increases our insights or refreshes us to plunge back into real world challenges. Shared virtual experiences on information infrastructures can complement books, plays, television, movies, and concerts in their ability to take us beyond the daily grind—the challenge is to move past escapism into metaphorical comprehension and catharthis.

Young people like magical alternate realities; and the entertainment industry profits by providing amusement parks, videogames, movies, and television programs that build on this fascination. Distance educators too can profit, in a different way, by building eerily beautiful environments for sensory immersion that arouse curiosity and empower shared fantasy, leading to guided inquiry. If we forswear distributed learning based on mystery, intrigue, and "edutainment," we risk losing the generation growing up with high-performance computing and communications to the mindless mercies of videogames.

Transforming Distance Education to Distributed Learning

Today, distance education is primarily used in selective situations to overcome problems of scale (not enough students in a single location) and rarity (a specialized subject not locally available). Such instruction is often seen as "half a loaf" pedagogy; better than nothing, but not as good as face-to-face teaching. However, the global marketplace and emerging information infrastructures are changing this situation. Educators must help all students become adept at distanced interaction, for skills of information gathering from remote sources and of collaboration with dispersed team members are as central to the future American workplace as learning to perform structured tasks quickly was to the industrial revolution. Also, by increasing the diversity of human resources available to students, distributed learning can enhance equity—as well as pluralism to prepare for competition in the world marketplace. Virtual classrooms have a wider spectrum of peers with whom learners can collaborate than any local region can offer and a broader range of teachers and mentors than any single educational institution can afford.

The distributed learning vignettes depicted above may seem financially implausible; where will schools, colleges and universities find the resources to implement these alternative pedagogical models? An analogy can be drawn to the early-1980s competition among cable TV vendors to receive exclusive franchises from communities. Those educators smart enough to participate in that bargaining process received substantial resources—buildings wired for free, dedicated channels, sophisticated production equipment—because the vendors knew public service applications would help determine who won. In the same manner, during today's much larger war in the information services industry, distance educators that have innovative alternatives to "talking heads" instruction can find vendors happy to share the costs in exchange for help with the regulators, legislators, and judges who are determining which coalitions will manage the nation's information infrastructures.

However, as with business, the evolution of technology creates new markets and expanded competitors for schools and colleges. As one illustration, prestigious universities may develop nationwide offerings of standard courses (e.g. PSYC 101) taught by telegenic, internationally recognized authorities. In such a strategy, high production-value presentations would be coupled with frequent, interactive teleconferences; mentoring via electronic mail; and occasional face-to-face meetings of locally enrolled students led by a practitioner. This approach would not intrigue learners interested in a residential college experience, but could be very attractive to students at commuter campuses. With sufficient economies of scale, this delivery method would have lower costs than our present system of similar standard courses duplicated at every institution. While many faculty would disparage this type of instruction, state legislatures could easily see such a model as an attractive way to cut their expenditures for higher education—a method applicable to every course for which a substantial textbook market exists.

In such an evolution of distance education, colleges and universities would be reshaped as profoundly as American business has been altered by technologies enabling the global marketplace. Given their responsibilities for socialization and custodial protection, public schools would be less affected by the erosion of geographic monopolies through distributed learning technologies. However, the home schooling and educational voucher movements see information infrastructures as an attractive alternative means of instructional delivery. If distributed learning is not incorporated into public schools' classrooms, teachers may find a decade from now that they have a smaller fraction of students enrolled and fewer taxpayers willing to provide funding.

An Illustrative Research Agenda for Distributed Learning

Advocates of distributed learning (including the author of this article) are making strong claims about its potential efficacy. However, scaling up research prototypes to mature, economically viable implementations is difficult, and promising technologies can falter when confronted with the challenging realities of everyday practice. What types of scholarly activity should be conducted to assess the potential of distributed learning? The discussion above suggests that research on the following issues is likely to be productive:

Instructional Design

- conducting future-focused needs assessments that examine new types of literacy and rhetoric emerging technologies are creating in the workplace
- studying the kinds of instructional designs effective for just-in-time, anyplace, on demand learning
- assessing the balance and sequence needed, for different types of problem solving, among presentational and constructivist pedagogical strategies
- contrasting the student motivation, instructional effectiveness, and cost of presentational teaching as opposed to learning-through-doing, using as a measure student performance on authentic real world tasks months after the end of instruction

Knowledge Webs

- studying how skilled teachers utilize analogical, case-based reasoning as a pedagogical strategy
- developing ways to embed knowledge via linked relationships rather than directly in hypermedia nodes
- designing support that aids learners in moving from assimilating archives to constructing their own personal knowledge
- evaluating how multiple representations (visual, auditory, symbolic) and nonlinear navigation affect learning
- assessing the optimal balance between implicit (structural) and explicit (interventionist) guidance in providing aid for different types of students and learning tasks

Virtual Communities

- studying the degree of telepresence produced by different levels of telecommunications bandwidth and the extent to which each level of affective and social interaction enhances various forms of learning
- evaluating the effectiveness of teleapprenticeships and telementoring in enhancing learner motivation and workplace skills
- contrasting the instructional effectiveness of field-based "classrooms with electronic walls" as opposed to technology-based means of bringing the real world to the classroom
- assessing the extent to which personal authenticity is enhanced for some learners by technology-mediated communication rather than face-to-face interaction

Shared Synthetic Environments

- studying the impact on learning of psychological phenomena characteristic of shared synthetic environments (e.g., disinhibition, fluidity of identity)
- evaluating the relative extent to which transforming symbolic data into sensory form (e.g., visualization, sonification)—or physically immersing the student inside a synthetic environment—aids learning various types of content
- contrasting the effectiveness of single-participant synthetic environments versus distributed simulation worlds with interactions among avatars

This list is illustrative rather than exhaustive, but does highlight the wide range of issues on which research is needed quite different from typical scholarship in the distance education community.

Conclusion

In a few years, high performance computing and communications will make knowledge utilities, virtual communities, shared synthetic environments, and sensory immersion as routine a part of everyday existence as the telephone, television, radio, and newspaper are today (Dede, 1994). Keeping a balance between virtual interaction and direct interchange will be important, however. Technology-mediated communication and experience supplement, but do not replace, immediate involvement in real settings. High performance computing and communications won't be a "silver bullet" that magically solves all problems of education; thoughtful and caring participation is vital for making these new capabilities truly valuable. Even then, at times a sloppy, handwritten note delivered through surface mail will mean more to the recipient than an instantly transmitted, elegantly formatted electronic message. New media complement existing approaches to widen our repertoire of communication; properly designed, they need not eliminate choices or force us into high tech, low touch situations.

How a medium shapes its users, as well as its message, is a central issue in understanding the transformation of distance education into distributed learning. The telephone creates conversationalists; the book develops imaginers, who can conjure a rich mental image from sparse symbols on a printed page. Much of television programming induces passive observers; other shows, such as Sesame Street and public affairs programs, can spark users' enthusiasm and enrich their perspectives. As we move beyond naive “superhighway” concepts to see the true potential impact of information infrastructures, society will face powerful new interactive media capable of great good or ill. Today’s “couch potatoes,” vicariously living in the fantasy world of television, could become tomorrow’s “couch funguses,” immersed as protagonists in 3-D soap operas while the real world deteriorates. The most significant influence on the evolution of distance education will not be the technical development of more powerful devices, but the professional development of wise designers, educators, and learners.

References

Bruckman, A. (1992). Identity workshops: Emergent social and psychological phenomena in text-based virtual reality, Cambridge, MA: Massachusetts Institute of Technology.

Christel, M. (1994). The role of visual fidelity in computer-based instruction. *Human-Computer Interaction* **9**, 183-223,.

Cognition and Technology Group at Vanderbilt University. (1992). The Jasper series as an example of anchored instruction: Theory, program, and assessment data. Educational psychologist, 27(3), 291–316.

Cooper, E. B. W., Borovoy, R., Grant, W., & Bellamy, R. (1994). Tools that support iteration, collaboration & reflection. Proceedings of the eleventh international conference on technology and education. Austin, TX: University of Texas.

Dede, C. (1995). The Evolution of Constructivist Learning Environments: Immersion in Distributed, Virtual Worlds. *Educational Technology* **35**, 5 (September-October), 46-52.

Dede, C., & Lewis, M. (1995). Assessment of emerging educational technologies that might assist and enhance school-to-work transitions. Washington, DC: National Technical Information Service.

Dede, C. (1994). The Technologies Driving the National Information Infrastructure: Policy Implications for Distance Education. Los Alamitos, CA: Southwest Regional Educational Laboratory.

Dede, C. (1992). Education in the 21st Century. *Annals of the American Academy for Political and Social Science* **522** (July), 104-115.

Domeshek, E. and Kolodner, J. (1992) Toward a case-based aid for conceptual design. *International Journal of Expert Systems* **4**, 2, 201-220.

Ferguson, W., et al. (1991). ASK systems: An approach to the realization of story-based teachers. *The Journal of the Learning Sciences* **2**, 95-134.

Fontana, L., Dede, C., White, C., and Cates, W. (1993). Multimedia: Gateway to Higher-order Thinking Skills. 1993 Proceedings of Selected Research Paper Presentations, Association for Educational Communications and Technology (351-364). Arlington, VA: Association for Educational Communications and Technology.

Goldman, S., Pellegrino, J., & Bransford, J. (1994). Assessing programs that invite thinking. In E. Baker & H. O'Neil (Eds.), Technology assessment in education and training. Hillsdale, NJ: Lawrence Erlbaum Associates.

Kass, A., Dooley, S., & Luksa, F. (1994). The broadcast news project: Using broadcast journalism as a vehicle for teaching social studies (Research Publication 40). Evanston, IL: Institute for Learning Sciences, Northwestern University.

Laurel, B., Oren, T., and Don, A. (1990). Issues in multimedia interface design: Media integration and interface agents. in The Association of Computing Machinery Computer-Human Interface Conference, 1990. New York: The Association of Computing Machinery.

Levin, J., Waugh, M., Brown, D., & Clift, R. (1994). Teaching teleapprenticeships: A new organizational framework for improving teacher education using electronic networks. Machine-Mediated Learning, 4(2 & 3), 149–161.

Means, B., Schlager, M., & Poirier, C. (1994). Distant mentor: Using technology to support collaborative learning at a distance. Menlo Park, CA: SRI International.

Orlansky, J., & Thorp, J. (1991). SIMNET — an engagement training system for tactical warfare. Journal of Defense Research, 20 (2), 774-783.

Pea, R. D. (1993). The collaborative visualization project. Communications of the ACM , 36(5), 60-63.

Repenning, A., & Sumner, T. (1995). Agentsheets: A medium for creating domain-oriented languages. Computer, 28(3), 17-25.

Rheingold, H. (1993). The virtual community: Homesteading on the electronic frontier. New York, NY: Addison-Wesley.

Salzman, M., Dede, C., & Loftin, B. (1995). Learner-centered design of sensorily immersive microworlds Using a virtual reality interface. In J. Greer (Ed.), Proceedings of the Seventh International Conference on Artificial Intelligence and Education, pp. 554-564. Charlottesville, VA: Association for the Advancement of Computers in Education.

Smith, M. (1992). Voices from the WELL: The logic of the virtual commons. Los Angeles, CA: Department of Sociology, University of California. Los Angeles.

Sproull, S., & Kiesler, S. (1991). Connections: New ways of working in the networked world. Cambridge, MA: MIT Press.

Stevens, S. (1989). Intelligent interactive video simulation of a code inspection. Communications of the ACM, 32(7), 832–843.

Turkle, S. (1984). The second self: Computers and the human spirit. New York: Simon & Schuster.

Weitzenbaum, J. (1976). Computer power and human reason. San Francisco: W.H. Freeman.