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THE COLLABORATIVE VISUALIZATION PROJECT

Roy D. Pea

How will learning take place as we enter the next century?

It seems necessary to focus broadly on new models for learning that transcend the antiquated conceptions of education found in most formally organized classrooms and training sites. Rather, we must focus on understanding and supporting learning in entirely new ways, with vital attention to the skills of social interaction and participation in new activities that currently constitute life-long learning in working and living communities. In contrast to learning-*before*-doing, which is the model of most educational settings, I would like to encourage attention to what I call learning-*in*-doing. Learning-in-doing is a model in which learners are increasingly involved in the authentic practices of communities through learning conversations and activities involving expert practitioners, educators, and peers. A prototype example has been the National Geographic Society KidsNet Project, in which children in thousands of elementary school classrooms investigated acid rain in their communities, pooled their data over networks, and carried out inquiries about why regional differences occurred in their data [5]. The questions the students addressed were current concerns in scientific practice, and they learned scientific concepts, research strategies, data collection, and analysis techniques through the doing of science rather than being taught about science as observers. We thus see science learned by *participation* rather than *preparation*.

Learning-in-doing requires interactions among groups that traditionally have been separated by the institutional boundaries of work and school. Advances in high-performance computing and communications [9] offer enormous potential for linking these communities in ways meaningful for learning. By collapsing spatio-temporal barriers through the construction of distributed multimedia learning environments, we may enable greater intimacy and authenticity in the learning process. Such technologies can be used to facilitate the return of successful learning models that existed prior to formal schooling, such as apprenticeship and long-term mentoring.

By fundamentally relying on information networks and remote multimedia services, distributed multimedia learning environments, or DMLEs, extend teaching, learning, and material resources beyond the limits of individual classrooms [10]. Network and multimedia technologies offer opportunities to increase the informational and interactional world of the learner through access to diverse databases, the possibility of collaborative projects with remote participants, and access to a wide group of experts and others with whom the learner can engage in conversation about a subject area, task, or project. While such expertise is now geographically dispersed and isolated, an increasing interconnectedness of learning environments is inevitable.

The CoVis Project as a DMLE Example

The functionalities of DMLEs are being demonstrated in a new high school-based National Science Foundation project on Collaborative Visualization we are conducting at Northwestern University.[1] We will be developing and studying a "testbed" consisting of an advanced network that integrates telecommunications, multimedia computing, and new collaboration software for state-of-the-art investigations of the potentials of collaboration and scientific visualization technologies for supporting science learning and teaching. This network will initially include two Chicago-area high schools (Evanston and New Trier), university scientists, science museum and science curriculum resources, learning researchers from three institutions, and a broadly based group of science teachers throughout the U.S. devoted to fostering project-enhanced science learning.

The CoVis project relies on innovative partnerships with Ameritech, Bellcore, The Exploratorium Science Museum, University of Illinois, Urbana-Champaign/National Center for Supercomputing Applications, ScienceKit Inc., Technical Education Research Center, and the University of Michigan. Our project vision is to establish collaborative technology-learning environments, or "collaboratories," that enable project-enhanced science learning among remote project partners using advanced telecommunication networks. This project develops the learning

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[1] Louis Gomez of Bellcore and Elliot Soloway of the University of Michigan serve as Co-Principal Investigators of the CoVis Project. All contributions at our partnership institutions cannot be listed, but project reports can be requested (pea@nwu.edu).

perspective known as Project Enhanced Science Learning (PESL), which is based on learners' engagements in authentic scientific inquiries through apprenticeship. Traditionally, such inquiry has been enabled by dynamic interactions among learners and a teacher who are in close physical proximity. Yet scientific and business work group practice using Internet and high-bandwidth services recognizes that not all partners necessary to an interaction can be colocated [6]. This project uses frontier technologies to extend the collaborative reach of educational arrangements to include widely dispersed expertise among learners, teachers, scientists, and learning researchers. For example, our collaboration with scientists at the National Center for Supercomputing Applications provides learners with access to subject-matter experts, visualization tools, and vast databases in the field of atmospheric sciences. Students will work collaboratively in project investigations on topics such as severe storms; weather forecasting; study of air masses, weather fronts, and air pressure systems; ozone depletion trends; and global warming.

Focusing on Collaborative Visualization

Because of the nature of the subject matter, and the goals of our models for learning, we have extended the educational media beyond text-only asynchronous email, as in National Geographic Society KidsNet, to include local- and wide-area multimedia networks. Such broadband networks, in our case a combination of primary-rate ISDN and HDSL.[2] enable highly interactive communications with rich media exchange among learning partners through the implementation of the multiuser multimedia synchronous (MUMMS) applications to be developed. Shared work spaces and two-way audio/video connections allow for collaborative visualization of science phenomena, data, and models through technologies that provide the option for "What You See Is What I See" (WYSIWIS) functionality, but that also allow private work spaces.

Scientific visualization technologies, now commonly used in the scientific research community, provide for much more intuitively comprehensible representations of complex numerical data used in the research activities of sciences such as meteorology, oceanography, molecular biology, chemistry, and astrophysics [13]. Collaborative versions of these technologies will allow scientists to establish real-time audio/video connections with their colleagues, in the context of the sharing of computer windows across the network in which scientific data and models can be pointed to and discussed at a distance. *Collaborative visualization* thus refers to development of scientific knowledge which is mediated by scientific visualization tools in a collaborative context. The CoVis Project seeks to understand how science education could take broad advantage of these capabilities, providing motivating experiences for students and teachers with contemporary science tools and topics.

We will be crafting new software applications—a Collaborative Science Workbench and Science Learning Resource Directory—to sustain collaborative visualization activities across remote classrooms and other sites for day-to-day, project-enhanced science learning. Functions to be modified for student use will include informal video conferencing [3] (a variant of Bellcore's *Cruiser*™ application, scientific visualization tools in regular use by research scientists [11] (such as the *NCSA Scientific Visualization Tool Suite*, and *Wxmap* for customizable surface weather map display[3]), and, most centrally, shared communication windows and a collaboratory notebook that will support research phases in PESL in which project team participants refine questions and select project topics, design procedures for data collection, negotiate and document study objectives, collect data, and conduct sense-making activities with their data, culminating in results such as a multimedia report of the results of their project investigations.

The CoVis Project seeks to determine the potentials of high-bandwidth networking for the design of future distributed multimedia science-learning enviornments. Just as banking was a place-based activity until the advent of ATM machines, science education is now largely a place-based activity. Emphasis will be placed on geographically dispersed teams of students, working together to accomplish tasks associated with science project investigations, with teachers and scientific mentors as guides. Computers and communications technologies are integrated to serve the learning enterprise. As the next decade brings relatively low-cost networked multimedia interpersonal computing to an increasingly wider market, we hope CoVis Project findings will guide the effective use of interpersonal collaborative media for science education.

Our current designs for the CoVis testbed as a DMLE utilize advances in a number of areas of computer technologies, consumer electronics, and telecommunications. They include:

- Coder-decoder (or "codec") technologies using signal compression chips to provide for the complex conversion of information-dense analog audio/video signals into digital information for two-way multimedia communications. Developments in compression algorithms, in interframe and intraframe processing, and in specialized hardware have been rapid lately, although full-motion video rates of 30fps are elusive. As of December 1992, industrial codecs have just dropped to the $10 thousand range. Many companies have announced or released desktop videoconferencing systems. In the CoVis Project, each workstation in-

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[2] Primary-access rate ISDN is the level of Integrated Services Digital Network service that provides 23B + D channels (where the bit rate for each channel is 64Kb/s), which can be configured to support audio/video and shared-data telephony. HDSL, or High bit-rate Digital Subscriber Line, is a relatively new technology which provides digital connectivity without fiber. It allows transmission over copper of repeaterless T1 traffic (i.e., 1.544Mb/s over 2 pairs) for up to 12,000 feet from the central office. See [7].

[3] To obtain the NCSA software, use FTP 141.142.20.50., or for a catalog, send electronic mail to docorder@ncsa.uiuc.edu.

cludes a codec for the audio/visual components of CoVis "calls" among remote participants or groups. The collaborative, shared windowing and notebook aspects of CoVis connections are handled over a "virtual ethernet," or WAN infrastructure.

- The WAN infrastructure includes the various telecommunication networks used in the Collaborative Visualization connections, such as NSFNet, and high-bandwidth rates over local and long-distance common carriers up to 1.5Mb/s.[4] In the CoVis Project, these broadband services support our technical needs for remote team members to engage in audio/video conferencing and to use visualization graphics (e.g., weather maps) in shared data windows as "conversational props" for their collaborative investigations.
- Switching technologies enable software applications in DMLEs to make the connection to specific addresses in a network for remote servers or to other users, and enable data flow and access control. It is one thing to pass around video within a LAN to network addresses, quite another to sustain full wide-area, national, point-to-point, and point-to-multipoint connectivity. The CoVis Project uses the public-switched telecommunication infrastructure of current and planned services to enable connection management for the media-rich conversations among participants in the CoVis project collaborations [1].[5]
- Multimedia servers of various kinds will be used in the CoVis network testbed sites, depending on the site and application, including CD-ROM, videodiscs, jukeboxes, and gigabit hard-disk drives for storing software-only digital video.
- Multimedia-capable personal computers with interfaces to communication networks play an essential role as the CoVis workstations.

Our CoVis Project explores the broad range of architectures to support learning that will be made possible by widely available rich information networking. Imagine carrying a small IMT device (interactive multimedia technology) around with you that is ISDN ready, and like an advanced cellular phone, you can call out or be called. But instead of connecting only to voice, you can connect to audio/video conferencing and shared-data applications. You can find parties who have the same interests as yours and who wish to work on learning projects together. You can engage in diverse workgroups, as a tele-apprentice, tele-mentor, or member of a tele-taskforce [7].[6]

Our observations and discussions with learners, teachers, and disciplinary scientists who use prototypes of our software applications over the course of the project will serve as the basis for the ongoing participatory design of authentic science-learning architectures that enable collaborative visualization of science in action. These learning environments will provide pedagogy and social protocols that authenticate the science-learning experience in classrooms, with the potential for links to homes and work environments. The outcomes which we seek, based on more valid performance assessments that are a result of students' network and school-based interactions, are greater motivation to learn and enhanced science learning.

Scaling Up DMLEs

How will progress be made toward the universal information networking that DMLEs require? As we see the merging of computers, consumer electronics, telecommunications, network and cable television, and media publishing, the contributions [2] of diverse industry sectors to these new technological developments make it uncertain how market forces will support the development of DMLEs over the next decade. But low cost and wide availability is likely. Expectations are high for large-volume pricing of the requisite multimedia PC commodity boxes that consumer electronics companies such as Sony, Philips, Sharp, Casio, Toshiba, and computer companies such as Apple, IBM, and Hewlett-Packard are entering the marketplace to provide. These "information appliances" integrate desktop productivity applications with telecommunications, fax, and other functions. For network and common carriers of these information packets, broadly divergent infrastructures are under development.

The year 1992 was dense with news of joint ventures and negotiations. First, there was the important U.S. Congressional legislation, S. 272, sponsored by (now Vice President) Albert Gore, authorizing about $3 billion in the High Performance Computing Bill of 1991 to facilitate the development of a National Research and Education Network using high-performance computing and communications to create the national data highway for digital communications across universities. As a result of substantial educator and researcher enthusiasm and lobbying, K–12 schools were also included.

In other developments, long-distance and local telephone companies are seeking to use codecs to allow for multimedia communications over existing copper wire, to accelerate the pace of fiber optic installation replacing copper, and to receive FCC approval to produce and not only distribute multimedia information services. Cable system operators, in some cases in cooperation with telephone companies, are developing switching capabilities to take advantage of their broadband infrastructure. The prospect of interactive video services has led to widely touted negotiations between computer companies and national cable system operators such as IBM and Time-Warner, and Hewlett-Packard and TV Answer Inc. (a wireless data service company). The major cellular-telephone carrier McCaw is teaming with Oracle, a leading database software company, to develop FCC-proposed, one-way radio-based data network services

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[4] Long-distance carriers AT&T, Sprint, and MCI, and many of the larger telcos have announced their planned introduction during 1992–1993 of the very fast SMDS (switched multimegabit data service), which will provide broadband speeds of 155Mb/sec and up later in this decade.

[5] Bellcore's Touring Machine software will handle the complexities of connection management among CoVis sites.

[6] You could also dial up and browse multimedia services, electronic magazines, and play with edutainment and virtual reality arcades that support learning, although these uses are not an emphasis in our work.

that would "piggyback" digital signals on existing radio transmissions, at fast rates of 1.5Mb a second. Wireless broadcasting systems to be offered by new joint ventures from IBM-Motorola and BellSouth-Ram Broadcasting carve out yet another option.

How these options will develop as distinct markets and services is anyone's guess. Video on demand (TV and movies), education and training, home shopping, banking, information services, food and service ordering, and game show participation are among the applications touted as likely. Many of these functions have broadband one-way, and narrowband interaction (control, audio) returning from the user. The open question is not whether high-bandwidth (1.5Mb and beyond) and multifunctional digital services can be provided, but how such services will come to be structured, architected, and priced to meet national learning needs, given concrete experiences in learning environments with different software applications and uses. But the competition in this general area of consumer electronics for interactive multimedia using telecommunications cannot but help the speed with which DMLE functionalities become available to the nation's learners.

The Challenge of Establishing Effective Pedagogy for DMLEs

After the creation of hardware and software architectures for DMLEs, the central and perhaps more difficult issue is how to make activities using them most supportive for learning. Beyond the databases and multimedia archives, what use scenarios across settings of learning ranging from schools to homes to community centers, will take best advantage of the opportunities these new media-rich communication media may offer?

What pedagogical models will need to be developed for DMLEs to be successfully implemented in schools and other learning settings? For example, experience already suggests these models will require extensive commitments for teacher-professional development, since new roles for teachers as guides rather than as authorities challenge existing classroom practices [12]. While there is a high level of receptivity and optimism for the use of telecommunications and computer technologies in schools throughout the U.S., the pedagogical models on which this enthusiasm is based are greatly varied, ranging from learner centered to teacher centered. While this diversity of learning models is not problematic in and of itself, it makes it difficult to coordinate support for nationwide technological resources and infrastructure. Since schools are notoriously underfunded, it makes sense to plan, perhaps through federal policy, for a nationwide technological infrastructure. What is the risk otherwise? The answer is that schools will become locked in obsolete technologies that limit the learning potentials of learners. It would be wise to highlight such issues in the evolution of current arguments [4] on which regulatory policies for electronic media will best serve the public interest in terms of the First Amendment provisions on access to information. Surely the learning needs of our nation will be among the foremost beneficiaries of a sound policy.

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