J6.5 **CoVis: A National Science Education Collaboratory**

Mohan K. Ramamurthy and Robert B.Wilhelmson
Department of Atmospheric Sciences, University of Illinois, Urbana, IL 61801
and
Roy D. Pea, Louis M. Gomez and Daniel C. Edelson
The School of Education and Social Policy
Northwestern University, Evanston, IL 60208

1.0 Introduction

Human interactions have largely been shaped by physical space. Except for a few technologies like the telephone, fax and perhaps electronic mail, the way we work, learn and play has been constrained by geography. This will change with the National Information Infrastructure (NII) as it creates a new "place" for human activities. This confluence of computing, communications, and networking technologies is expected to touch all aspects of American life. What will the NII mean to schools and learning communities, for science education and teacher development?

There is not one answer. Just as school buildings and the communities they house are shaped by factors like population density, local economy, and prevailing views of pedagogy, the NII will take shape in learning communities in diverse ways. No single research and development effort can be a model of all of these. The Learning Through Collaborative Visualization" or more simply, CoVis, is an NSF-NIE testbed that focuses on how to use applications of high performance computing and communications technologies (HPCC) to support science education reform. CoVis is centered at Northwestern University and UIUC's Department of Atmospheric Sciences is a key participant in CoVis development. The CoVis community includes teachers and students, research scientists, museum-based informal science educators, and science education researchers, in a "distributed multimedia learning environment" (Pea & Gomez, 1992a).

The CoVis philosophy is grounded in a constructivist approach to science learning and teaching that emphasizes authentic, challenging projects as the nucleus of activities for "learning communities" which include students, teachers, scientists, and other participants. The goal is to create learning communities that more closely resemble the collaborative practice of science, which increasingly relies on HPCC technologies to create "collaboratories" (Lederberg & Uncapher, 1989). In CoVis we have been using HPCC to support the formation and work activities of learning communities with media-rich communication and scientific visualization tools in a highly-interactive networked collaborative context (Pea & Gomez, 1992b; Pea, 1993). CoVis has focused on three areas—project-enhanced science learning, collaboration, and scientific visualization—as means for transforming science education. In this process, we have worked with high school teachers in development activities to transform their classrooms from traditional teacher-centered classes to project-enhanced classes in which students learn about science through personal and group inquiries.

2.0 CoVis Network

To bring the practices of science to classrooms, the CoVis network extends today to Evanston Township High School (ETHS), New Trier High School (NTHS), Northwestern's School of Education and Social Policy, the Department of Atmospheric Sciences at University of Illinois, Urbana-Champaign (UIUC) and the Exploratorium Science Museum. The network enables high school students to join with other students at remote locations in collaborative groups. Students also use the network to communicate with university researchers and other scientific experts in teleapprenticing relations. Our experiences in constructing a collaboratory highlight *system integration* and *new software design and implementation in classrooms*, two challenges that will face all National Infrastructure for Education (NIE) testbeds and other NII efforts.

One major goal of the CoVis project is to combine prototype and off-the-shelf applications to create a reliable, networked environment that showcases HPCC technologies for K-12 learning communities. Our key result is that the network is running and in daily use by approximately 300 people, mainly high school students. The challenge of this effort has been to take a collection of technologies, many only demonstrated or tested in small-scale lab and demo situations, and place them into daily service in demanding conditions. Our progress culminated in a stage-by-stage installation during Fall 1993 of the CoVis network testbed using public-switched ISDN services.

The network design and implementation is the result of intensive collaboration between Northwestern, Ameritech, and Bellcore, and it uses the Primary Rate Integrated Services Data Network (PRI-ISDN) as the transport layer for the CoVis network. In the immediate term, ISDN is the network service that offers the best combination of high bandwidth and ubiquity in a switched service. Bellcore predicts that by 1996 more than 70% of the nation's population will have access to ISDN service. A key benefit of ISDN for the CoVis Project is that its bandwidth can be broken up into call channels, which can be dedicated to different functions. We used this feature to create a two-function "overlay" network that gives student workstations access to both ethernet-based packet-switched data services and circuit-switched desktop audio/video conferencing. One group of 6 64 kb/s ISDN channels is being used to create a virtual ethernet to each school running at 384 kb/s. With compression, this network has a performance close to 1 Mb/s. Other channels provide 384 kb/s switched video teleconferencing for each of the CoVis workstations in the schools. Since ISDN is "public switched service," CoVis participants can, in principle, place calls to any other ISDN line in the country.

Within each school, the CoVis network supports synchronous and asynchronous communication. The CoVis Project supplied each school with five workstations per classroom plus one workstation at an alternative location for student access outside classes. All workstations are connected to an ethernet which is bridged via ISDN lines to the Internet. The CoVis communications and collaboration suite includes the Collaboratory Notebook (see below), e-mail, file transfer, Usenet news (filtered for suitability), and access to the World Wide Web.

In addition to these applications, the communications suite includes *screen sharing* and *video teleconferencing*. CoVis participants may collaborate synchronously through screen sharing, in which one user can see exactly what appears on the screen of another user, even though at a distance, using the commercial application Timbuktu, produced by CoVis' industry partner Farallon Computing. Desktop video teleconferencing is another critical element of the CoVis testbed, and examinations of its utility for learning and teaching are a key part of our research. Students use the Cruiser™ application, provided by Bellcore (Fish et al., 1993), to establish video teleconferencing calls. Cruiser allows students to place calls, both point-to-point and point-to-multi-point, to other CoVis addressees by selecting the name of the individual(s) from a directory. Cruiser is a client application of Touring Machine, the network management software developed by Bellcore (Bellcore Information Networking Research Laboratory, 1993) which manages the heterogeneous resources (e.g. cameras, microphones, monitors, switch ports, directory services) in the CoVis network. It is significant that CoVis Project needs and Ameritech (one of the baby Bell companies) interests drove the first integration by Bellcore of Touring Machine into an ISDN network. To our knowledge, CoVis is the first school-based application of ISDN desktop video conferencing.

3.0 CoVis Testbed Components

The CoVis testbed seeks to provide students with authentic scientific inquiry experiences across geographically dispersed sites. To succeed in this endeavor, it has been necessary to develop two new application environments: (1) a groupware application to support collaborative student inquiry, and (2) tools to make scientific investigation techniques, specifically data visualization, accessible to high school students.

<u>Collaboratory Notebook</u>. The Collaboratory Notebook is a central and unique element of the CoVis environment, serving several roles for project-enhanced science learning (Edelson & O'Neill, 1994). Briefly, the Notebook is groupware for scientific inquiry. It is a shared, hypermedia database built on top of an Oracle database connected to the Internet. The Notebook provides a place for students to record their activities, observations, and hypotheses as they work on projects. It provides a means for planning and tracking the progress of a project and for collaborators to share and comment upon each other's work. Within the Notebook, there is a small, fixed set of page and link types. These types provide a scaffold intended to assist students in structuring their open-ended inquiry process. For example, a page that records a set of visualization activities can be linked to questions raised during those activities. Those questions can, in turn, be linked to conjectures that address the questions, and to plans for investigating the questions. The goal of the Notebook is to provide students with a "scaffolding structure" for open-ended scientific inquiry, and a mechanism for collaborative work within or across schools.

<u>Scientific Visualization Environments</u>. Today atmospheric and other scientists use data visualization tools and work with standard data sets routinely (e.g., Searight et al., 1993; Wilhelmson, 1994; Wilhelmson et al., 1994). These tools and data sets are mainly useful to highly specialized members of technical communities (Gordin & Pea, in press). To allow students to work with the same data sets as scientists in similar ways, we have adapted the tools used by atmospheric scientists to be appropriate for high school students. To date, CoVis has developed two such visualization environments, The Climate Visualizer and The Weather Visualizer, and is developing a third, The Greenhouse Effects Visualizer. All three visualization environments are tightly integrated with the Collaboratory Notebook.

(1) The **Climate Visualizer** allows students to construct scientific visualizations to explore global climate patterns (Gordin, Polman & Pea, in press). It contains 25 years of twice daily weather values (temperature, pressure, and wind) for most of the northern hemisphere. In the Climate Visualizer, temperature is encoded as a raster color image, altitude as contours, and wind as arrows (or vectors), with an optional overlay showing continents. Students can interactively sample values in a visualization by selecting locations

with a mouse and can view trends across time by subtracting one image from another. For example, seasonal differences can be seen by subtracting January temperature from July. Such a visualization might highlight the differing properties of land and water in absorbing heat. The Climate Visualizer is a front-end to Spyglass Transform, a commercial visualization package, and uses a data set available on CD-ROM from the National Meteorological Center's Grid Point Data Set.

(2) The **Weather Visualizer** (Fishman & D'Amico, 1994) is a tool for examining current weather conditions throughout the U.S. in the form of: satellite images in visible and infrared spectrums; customized weather maps displaying up to 14 different variables at five different altitudes for any region or city in the U.S. at a variety of zoom factors; "six-panel images" displaying temperature, pressure, wind speed, wind direction, dew point, and moisture convergence for the entire U.S.; and textual reports providing local conditions and local and state forecasts for all reporting stations. The Weather Visualizer is implemented as a front end to wxmap, a UNIX program developed at the University of Illinois. The data for the Weather Visualizer currently comes from our collaborator University of Illinois' Weather Machine, which, in turn, receives data from the National Weather Service's Family of Services DD+ feed and from GOES satellites (Ramamurthy et al., 1992). Through its gopher server for current weather images and information, the Weather Machine at UIUC is providing a valuable service to a community well beyond K-12, including researchers and educators nationwide. Over 100,000 requests for images and text are received per day in peak usage periods (Ramamurthy & Kemp, 1993; Ramamurthy et al., 1994; Ramamurthy & Wilhelmson, 1993).

(3) The **Greenhouse Effects Visualizer** (Gordin, Pea, & Edelson, 1994) coordinates a collection of data sets that include the sun's incoming radiation (insolation), the amount reflected by the earth (albedo), the temperature on Earth's surface, and the earth's outgoing radiation, to allow students to examine the balance of incoming and outgoing radiation for the earth (Greenhouse effect.)

<u>Multimedia Modules</u> In addition to providing real-time weather information, one of UIUC's main contributions to CoVis has been the development of an array of Internet-accessible multimedia instructional modules, consisting of text, color diagrams, movies, audio, and scanned images, that introduce and explain a variety of important concepts in atmospheric sciences as they arise in project inquiry. These multimedia instructional modules on various topics are being developed for use at the high school level, and are available from *The Daily Planet*™ server, A Web server at UIUC. The modules are being tested at the two current CoVis schools in the Chicago area, and they are being revised and refined based on the feedback from them. Such multimedia-based instruction provides an alternative approach to learning, one in which the student, through interaction with the computer, becomes actively involved in the learning process.

The first set of modules that has been developed describes pressure and wind, various types of weather maps, satellite and radar images, and their use in weather analysis and forecasting (Ramamurthy et al., 1994, Sridhar et al., 1994). Through the use of colorful diagrams, video clips, text, and audio narration, a student becomes acquainted with topics like pressure, high and low pressure centers, and the balance of forces that generate winds. CoVis teachers at the two Chicago-area schools incorporate appropriate resources from these modules and our online weather databases into their courses. Other modules currently under development include a: (1) Cloud Catalog, (2) Guide to Atmospheric Optics, (3) Tornado Spotters Guide, and (4) Severe Storms Guide. The Tornado Spotters Guide, in addition to informative text and graphic inserts, contains clips of live tornado footage. The ultimate goal is to deliver extensive and broadly useful multimedia resources over the Internet, to support very diverse project inquiries. The multimedia modules are not only improving education at the K-12 level by making it more interactive through the use of advanced computer technologies, but are also providing a collection of curriculum resources for the whole Internet community.

4.0 Use of the CoVis Tool Suite

CoVis technology is in daily use by the entire community. A measure of use can be provided by a look at application uses: From Jan-Mar 1994, CoVis school-based users launched approximately 14,000 applications. The overwhelming proportion of use is of Internet tools (e.g. e-mail, Gopher) at 59%, with an additional 13% representing CoVis tool launches (e.g. Collaboratory Notebook, Climate Visualizer, Weather Visualizer), 13% graphic tools, 8% word processors or spreadsheets, and 7% utilities and games. The CoVis community has not had time to develop well-defined patterns of tool use, but early impressions are that CoVis applications are very popular and may increase in use percentage with familiarity. Video conferencing was introduced to students mid-January '94. We found considerable increases in HPCC uses for the student population from Fall 1993 to Spring 1994.

In its ongoing research, the CoVis Project studies and reports on the design, implementation and use of these network-based and media-rich learning environments for an audience of learning scientists, educators, educational telecommunications policy analysts, and corporations who are defining "new media" applications and services. CoVis is examining pedagogy and technology questions such as: How should next-generation information networking be implemented to spur science educational reform? What are proper educational support roles for networked multimedia technology, desktop videoconferencing, and other next-generation communication and computing technologies? What are the details of a pedagogy which will support diverse communities of practice? How can today's teachers transform their work-roles in new learning environments? What new curriculum materials and tools will be needed to support revitalized science curriculum that keeps pace with developments in the sciences and changes in the national information infrastructure?

5.0 New Developments in CoVis

To significantly scale the CoVis testbed over the next three years, we have developed strategies for realizing the innovative concepts and benefits of the CoVis broadband technology approach for a spectrum of schools with very different levels of technological readiness and infrastructures. We have defined three levels we describe in terms of a Technology Pyramid. Each level corresponds to a specific richness of technology infrastructure. At Level 1, the Pyramid's apex, will be a relatively small number of schools with the complete suite of CoVis technologies, including new applications and services to be developed. Moving down the pyramid, Levels 2 and 3 represent increasingly larger numbers of schools, requiring successively lower levels of technology infrastructure. Our goals are to include as many schools as possible to leverage use of the more common levels of installed technology in our testbed, and to define affordable entry levels for migration paths to higher levels of the pyramid. The levels are not rigid but serve as a realistic representation of the spectrum of schools that will come to join the NII. Schools will migrate across levels in both directions and combine different capabilities within a building. Including schools at these diverse technology levels will enable us to provide key data concerning the cost-effectiveness of the different levels for educational networking connectivity for science education reform outcomes.

At the top of the pyramid representing our Level 1 sites, we will intensively work with a few schools but increase their number and diversity from our current 2 suburban Chicago schools (involving 12 classes) to six total schools by 1996-97. These schools will include urban, suburban, and rural sites and will cross states. In six Level 1 schools, we will continue exploring high-end HPCC technological infusion and implementation for schools at the cutting-edge (below). The considerable diversity of new sites at this level will help us to understand the challenges and particular benefits of adding high-bandwidth connections to schools in different types of communities, since their technical suite will approximate the current CoVis school profile: broadband data connections to the Internet (384Kb/s or better), and at least three desktop videoconference stations per school.

Schools at Level 2 of the pyramid will have similar data networks to Level 1 schools except for desktop video conferencing and video server access. However, through ordinary phone lines and screen-sharing, Level 2 sites can participate in audio teleconferencing and will have access to all CoVis software and materials via the Internet. Schools at Level 3 will have low-bandwidth connections to the Internet, via dialup, and will represent the typical network connection paradigm for U.S. schools today. Through SLIP or PPP protocols, they may access CoVis software and materials on the Internet, but will not have any form of synchronous conferencing. To support these Level 3 schools, we will be developing and distributing video tapes and CD-ROMs to help them take advantage of the materials/pedagogy we are developing throughout the CoVis Collaboratory testbed.

In adding new functionalities to the Collaboratory over the next three years, as described below, we seek to build on the existing CoVis network architecture in order to extend the range of ways that students, teachers, and other members of the community can communicate and collaborate with each other. In building and extending the CoVis technology infrastructure, our challenge continues to be taking innovations that have been used in limited ways in research tests and demonstrations and placing them into service so that they can reliably serve the needs of a demanding population.

(1) Software Environments to Support Collaboration. In the early years of the CoVis Project we have developed an architecture for collaboration that combines the Collaboratory Notebook, specially-developed software for collaborative inquiry, video conferencing, remote screen sharing, and a standard package of Internet tools. In the next several years, we will continue development of the Notebook as we extend from a single community of 12 classes to multiple communities of thousands of classes. This will involve, for example, the development of “libraries” of notebooks that will allow students to locate relevant prior work by other students through easy-to-use search mechanisms. In addition, it will be necessary to provide easy administration of the Notebook to school personnel. This goal will be achieved in collaboration with the National School Network Testbed Project at Bolt, Beranek & Newman (BBN) in Cambridge, Massachusetts. We will migrate the management of user accounts for the Collaboratory Notebook to BBN’s Copernicus server, which already supports many important administration functions for schools.

(2) Enhanced Video Conferencing Services. Today our video conferencing network is used for point-to-point video calls. As part of our new work on the CoVis testbed, we will have multi-point video conference calls available. This ability to involve participants in a variety of locations in a single call lets us extend how

the video network is being used to include two telepresence experiments.

(3) Video server. The CoVis video server will allow users to both view and record digital video in real time. Unlike current networked applications such as Gopher and Mosaic, the users will not have to download compressed video to the local workstation before viewing it. Instead, the video will be streamed live between the video server and the user's workstation, in either playback or recording modes. The video server will be supported by StarWorks™, a video applications server produced by industry leader Starlight Networks (Mountain View, CA).

(4) Geosciences Server. A multi-institutional design will be developed and implemented for a World-Wide Web Server for Geosciences Education to include tools, datasets, and diverse multimedia materials for use in K-12 science education involving the earth, atmosphere, and environment. Initial contributors to design and materials available over the server nodes will include Northwestern, UIUC, U. Michigan, U. Colorado, Exploratorium Museum, and select schools. Materials will include: datasets, editorially-reviewed student projects in Collaboratory Notebooks, directory services for participants, and a comprehensive indexing scheme. We will seek to assure compatibility of testbed science curriculum resources and activities with the leading state frameworks and national science education standards. This same server will provide the major dissemination vehicle for the project, and will include publications, papers, reports, images, animations, and brief QuickTime video clips to share its results on an ongoing basis with a broad community. For Level 1 schools that have video conferencing capability, the Geosciences Server will provide an interface to materials on the video server.

The ultimate goal of the server is to develop a new paradigm for Environmental Sciences education. Our consortium will develop an on-line weather laboratory, to provide interactive access to a wide range of weather information. An important aspect of the server is that it will provide access to observations, local forecasts, watches and warnings, satellite images and numerical model forecasts from any computer that is connected to the Internet. Not only will any computer on the Internet have access to the server, but we will also structure the information such that others who create their own servers can follow our model in setting up servers that point to ours.

The educational and informational material on the server will initially be focused on atmospheric sciences but will grow to include a broad range of earth science topics. One section of the server will be devoted to weather. The access to up-to-the-hour weather data that is currently available through CoVis Weather Visualizer will be augmented with historical data that covers recent years at daily or twice daily intervals and that covers major weather events during those years at hourly intervals. A second section of the server will be devoted to climate. An example of the resources to be available there is information drawn from the Midwestern Climate Atlas, which was recently prepared by the Midwest Climate Center at the Illinois State Water Survey. The statistics in the atlas include temperature, rainfall, snowfall, and extremes and probabilities of occurrence. In addition to these primary climatic elements, the atlas includes a variety of other derived variables such as heating; cooling; and growing degree days, growing season length, and frost dates. Most of the development of the server and the resources on it will be conducted at UIUC with close consultation on pedagogical matters from team members at Northwestern and the Exploratorium.

The server will also contain Exploratorium-produced Video Answers to FAQs (frequently asked questions). These will be produced multimedia responses to questions on geosciences created using Exploratorium resources (exhibits, materials, media) that are distributed on demand from Exploratorium World Wide Web and the CoVis Geosciences Server. These Video FAQ's will also be available for real-time viewing through the CoVis video server. This material will be developed based on participation in the Collaboratory activities and from responses from teachers and students. In addition, a video introduction to the museum will be available for the users to help them understand what they can get from the Exploratorium and to give a personal introduction to the museum and staff.

To increase the level of interaction between atmospheric scientists and CoVis students, UIUC will be conducting daily weather briefings via the Cruiser videoconferencing system to CoVis sites. These weather briefings will be tailored to the CoVis community, and offered by UIUC faculty and students. During these video weather briefings, we will illustrate, through interpretation and analysis of weather charts, satellite and radar animations, and forecast products, key concepts that will enable a student to conceptualize the structure and dynamics of the atmosphere. Students may also participate in discussions of weather processes as depicted by weather maps, and learn techniques of forecasting weather. The depiction of atmospheric kinematic and dynamic processes on weather charts will be emphasized. We plan to record and digitize some of the weather briefings and eventually make them available to the CoVis sites and explore the use of video server technologies in instruction and collaboration. Such video servers are currently under development at several places, including NCSA at University of Illinois, Urbana-Champaign.

6.0 Concluding Remarks

CoVis envisions widespread use of learning environments where next-generation communication and computing technologies enable students, teachers, scientists and other professionals to work together in networked communities focused on science education. Today CoVis is a small-scale working model of this vision in two high schools. in the next phase of the CoVis Project, we are poised to provide some of the key national research and development required to inform large-scale and cost-effective implementations of reform-oriented science educational networking. There are over 18,000 high schools and 12,000 middle/junior high schools in the nation. We will be developing and researching the CoVis testbed as a *National Science Education Collaboratory*, by systematically addressing the scaling issues inherent in achieving goals of *critical mass* of participation and in *diversity* of schools, teachers, students and other participants in such an enterprise. In addition, CoVis is expected to grow from a venue for addressing research and development questions to an experimental facility for informing governments and businesses about how to do the large-scale implementation of HPCC technologies within the NII in a cost-effective manner that meets the reform needs of school communities.

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