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ABSTRACT

Network Science projects are endeavors in which a number of classrooms conduct the same scientific experiment and pool their data using World Wide Web technology. This paper reviews selected findings from research on these projects and describes the recent Web applications that were developed in response to these findings. Findings indicated that many of the observed classes were engaged in genuine inquiry, innovation, and cooperative learning. The telecommunications technology also fostered a genuine sense of community among the participating schools. Findings also indicated a general absence of any analysis of the data these classrooms were collecting. Factors that contribute to the failure of classes to analyze and understand the data they collect are discussed including cognitive, curricular, pedagogical, and technological challenge. Suggestions for adapting the technology to respond to these challenges are presented including the use of Collaborative Learning Environments On-Line (CLEO), a Web space that makes it possible for anyone with an Internet browser to create a data-rich project. (JRH)

Working with Data in Network Science

Paper presented in the symposium

Tools for Learning:
How Technology both Masks and Illuminates Cognitive Dilemmas

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Introduction: Network Science

The Testbed for Telecollaboration at TERC is a three-year research project sponsored by the National Science Foundation on the use of the World Wide Web in "Network Science" projects. The Testbed project defines a Network Science project as an endeavor in which a number of classrooms conduct the same scientific experiment and pool their data using Web technology. All the classes can then analyze the data from each location. Network Science projects typically explore genuine scientific questions in a data-rich environment; they put the students to work to answer those questions using authentic research practices and standards; and they deploy the Internet to bring the classrooms into contact with discipline experts.

Two examples illustrate this concept. Sponsored by Tech 2000 in Illinois, EnergyNet involves 90 middle and high schools in an authentic science project. Working in teams, students at each school conduct a complete energy audit of their school building's energy use -- from heating and lighting systems to power use and building envelope. After analyzing their findings, they make recommendations to local school authorities about the cost and management of the energy in their school. The results of these audits are posted on the EnergyNet Web page.

Classroom Feederwatch is being developed by TERC and The Cornell Lab of Ornithology for grades 5-8 and is used by lower grades as well. Classroom Feederwatchers count the kinds and numbers of bird species that visit feeders placed in their school yard and then, using Web-based submittal and retrieval forms, they share their bird data with The Lab and with other students doing the project. Their analyses help scientists and Classroom Feederwatchers answer questions about changes in populations of bird species from month to month, year to year, and place to place.

The Testbed for Telecollaboration is a family of a dozen Network Science projects. It can be found on the Web at:

http://teaparty.terc.edu

This paper reviews selected findings from our research on these projects and describes the recent Web applications that were developed in response to those findings.

Research Findings

During the 1995-96 school year, we conducted a systematic study of four of the Testbed projects. The research consisted of classroom visits, interviews with teachers, students and administrators, surveys of teachers, and an analysis of the usage of the Testbed's Web pages and discussion groups. In this section, we report two findings from this research.

Innovations in Practice

Many of the observed classes in the Network Science projects were engaged in genuine inquiry and innovation. Teachers in these programs had organized students into cooperative groups. Students in the EN program were divided into teams that each explored one particular facet of the energy audit task -- electricity, building insulation, heating, gas, Internet communications, and so on. The work on these teams were combined into a single analysis of energy consumption and areas of potential saving that provided the basis for the recommendations to the school board.

As a result, students in the EN curriculum became experts in energy consumption in their buildings. They manifested this expertise in presentations to their local school boards that resulted in changes in energy-use policies in those schools. We were able to document this expertise when we were given an impromptu tour of the building by these students who pointed out the proposed energy-saving measures.

We also found that the telecommunications technology fostered a genuine sense of community among the participating schools. Teachers and students commonly share their experiences with one another. They also use the telecommunications to seek help from participating scientists and engineers who provide on-line support to the projects.

Finally, the projects in the Testbed for Telecollaboration were engaged in authentic problem solving and they worked collaboratively in this effort. They used a team approach and fashioned their findings as a formal report with recommendations for changes to policy to a governing body.

Absence of Data Analysis

At the same time that we found genuine innovations in teaching practice, we also found a general absence of any analysis of the data these classrooms were collecting. We observed moments when teachers appeared to misunderstand the purpose of the data. For example, teachers were often preoccupied with the task of filling the data table and failed to engage students in this opportunity for genuine problem solving. In one study, students were attempting to record the wind direction on a blustery day. They pointed out to their teacher that the wind was swirling around and their data entry form forced them to choose a wind direction. The teacher replied brusquely, "There is no entry for 'swirling.' We'll call it 'North.'"

Other projects had data sets that were too extensive for sensible analysis or used highly technical variables that compounded the difficulty of making sense of the results. The data submitted by classes were often left incomplete with no explanation or concern expressed by the students or the teachers. In some projects, we observed cases were the data were collected quickly and without an understanding of the underlying concepts. In a number of cases the data that classes had uploaded contained inaccuracies that were obvious when displayed, but even in those cases the students we interviewed were unconcerned. Since part of the purpose of sharing data is to gain some sense of accuracy or local variation, identifying errors is itself an important task of data analysis and yet this opportunity was typically overlooked.

Finally, we observed classes asking questions and then using the data they had collected to address those questions. However, by analyzing the use of the network server, we determined that few schools downloaded the shared data set and only one or two analyzed those combined results. In fact, we conclude that in most of these projects analysis of the shared data was not the centerpiece of the investigation. In short, these projects appeared to focus on collecting and sometimes sharing data but only very rarely on analyzing and understanding the results.

Contributing Factors

We believe that there are four factors that contribute to the fact that consistently in Network Science projects, classes fail to analyze and understand the data they collect.

Cognitive Challenge

That the task of drawing inferences from a set of data is cognitively challenging is well documented in the research literature. Many of the formal reasoning operations are absent in the logical thought of untrained adults. (Wason and Johnson-Laird, 1972). Probability and statistical thinking show the same resistance to instruction even in adults (Tversky and Kahnemann , 1974). Correlational reasoning is surprisingly difficult for high school students and adults, even when the tasks are posed as "real-world" problems (Kuhn, D., Phelps, E., & Walters, J., 1985).

This cognitive challenge also appears in studies of teaching statistics. For example, Konold found that high school students who have taken a hands-on class in data analysis in a post test interview persist in the naive habits of reasoning from particulars and ignoring group differences (Konold, et al. 1996). Perhaps in response to this challenge, statistics is typically taught as a set of theoretical formulas and test algorithms that make the underlying concepts all the more obscure (Rosebery and Rubin, 1989)

This cognitive challenge applies to both teachers and students. Any effort to engage problems in data analysis will require thoughtful guidance. In our observations of the Testbed classrooms we saw this cognitive difficulty displayed as teachers' uncomfortableness with a basic assumption of the projects that were often displayed as frustration and misunderstanding.

Curricular Challenge

Science classrooms in general do not engage in data-rich inquiry. When science labs require students to collect data relevant to a particular scientific phenomenon, the results are compared to the expected theoretical values. Deviation from those expectations are treated as errors in data collection.

Inquiry-based science, in contrast, uses scientific experiments to answer questions essentially for the first time. More like true science, these projects develop a an experimental procedure to answer a particular question; the data collected are analyzed in pursuit of an answer to that question.

For example, compare these two questions: 1) Does the quantity of gas given off when this acid and that base are mixed together match what is predicted by the theory of atomic structure? 2) Does isopropyl alcohol kill bacteria more effectively than a brand-name antiseptic? The first question has a more obvious "right" answer that can be used to check the results. The second does not.

The traditional curriculum often does not include data analysis as a topic nor does it deploy the skills of data analysis in pursuit of other curricular issues (Tinker, quoted in Karlan, 1997). In contrast, data analysis has a very important role in a curriculum that is designed around truly open-ended questions (Hancock, et al., 1992).

These curricular barriers were most evident in the high school science class settings. We found consistently that innovative Network Science programs only fit in the structure of the high school curriculum when they were offered as electives, clubs, or independent study projects. They did not become part of the curriculum in these cases but served as a supplement.

Pedagogical Challenge

A curriculum based on open-ended questions, those that can be answered with true experiments conducted by students, also requires a parallel pedagogy that enables inquiry, independence, and spontaneity. For example, often answering one question generates a second, very different question and as a result, eventually the class consists of small groups of students working independently on questions of their own making.

This situation, students working independently, poses a significant pedagogical challenge to the teacher. Providing instruction, scaffolding and guidance in a timely fashion is complicated. Large-group instructional practices are often useless. Assessing student learning creates another set of challenges because short-answer tests miss much of what students are engaged in. Consequently, the change to inquiry-based projects designed in part by the students themselves demand significant pedagogical shifts by the teacher (Coulter and Walters, 1996). Such shifts are further complicated by restricted schedules, short periods, and large class sizes.

We saw this pedagogical barrier in evidence as teachers adjusted the open-ended inquiry project to a more traditional teaching style. In some cases, teachers lectured on the basic concepts and then gave students specific assignments as exercises; the project instructed them to pose open-ended questions and form students into self-directed teams. Their lectures and assignments followed the curriculum precisely but did not follow the pedagogical guidelines. In some cases the teachers took full responsibility for seeing that data that the students had collected had been accurately uploaded to the shared database; again, they followed the letter of the instructions while missing its pedagogical spirit.

Technological Challenge

To these issues of cognitive challenge, novel curriculum, and innovative pedagogy, Network Science adds the burden of technology. Telecommunications in the classroom is new and relatively undependable. Not only must the teachers and students master the intricacies of connecting to an Internet service (via modem in most cases), but they must also figure out how to make that resource function effectively within the constraints of the rigid class schedule. On many occasions, we observed students trying to connect to an ISP only to be thwarted by faulty hardware, noisy phone lines, busy modem lines, or changing passwords.

Once the connection is made, the participants must learn to use the technology to exchange data and eventually to analyze their results. Many of the technical difficulties we observed are solved in some settings. The point here is simply that the technology in many cases remains a barrier rather than an enabler of learning.

Adapting the Technology to Respond to the Challenges

Given these findings, it is not surprising then data analysis receives short shrift in many science classrooms. Teachers often adopt a Network Science project because it affords an opportunity to use the latest technology rather than to pursue a particular question related to their curriculum. They are pressed for time and overwhelmed by a number of new challenges. They set for themselves reasonable priorities and analyzing the data of the study is not high on that list.

The data sharing of Network Science brings this challenge of data analysis in the classroom in sharp relief. Here we find classrooms spending valuable time and energy collecting and sharing data with their remote colleagues, but without an apparent interest in studying the combined results. We also find that the technology focused attention on this issue but it has not contributed in any noticeable way to a solution. It appears then that, even though it presents a possibly powerful learning opportunity, delivering the data to the classroom via technology is not sufficient for learning from those data.

We believe that with thoughtful scaffolding and technical support for teacher-initiated projects, Network Science classrooms will begin to approach questions of data analysis in an educationally sound fashion. We have developed a new Web-based authoring tool, called CLEO, to provide an environment in which we can test this idea.

CLEO (Collaborative Learning Environments On-line) is a Web space that makes it possible for anyone with an Internet browser to create a data-rich project. Visitors to CLEO can browse the library of projects, participate in a collaborative project, or author a new project of their own. Each CLEO project features a full description of the scientific or mathematical investigation, the complete data set for that investigation, and a discussion of the findings.

CLEO is designed to address the four challenges of data analysis identified in our research.

Cognitive challenge: In all CLEO projects, data analysis begins with a question generated by the classroom, giving teachers and students the opportunity to make sense of their numbers in a concrete and well-understood context. Also, the scaffolding for data analysis is thoroughly illustrated by examples taken from projects in the CLEO library.

Curricular challenge: CLEO includes a library of data-rich science and math projects, each with its own data and data-sharing opportunities; in selecting a project from this library, participating teachers can often find a specific project that matches their curricular goals.

Pedagogical challenge: Teachers can use CLEO in three very different ways, browsing the library of projects, participating in a data-sharing project or authoring a new project. Because of this flexibility of use, CLEO is easily adapted by teachers to their own pedagogical needs and teaching style.

Technical challenge: Using CLEO does not require any special skills or software; it is no more complicated than surfing the Web. Of course, as with all Network Science projects, CLEO requires a reasonable connection to the Web.

Our hypothesis is that the CLEO Web space can contribute to students' understanding of data analysis. We also believe that this authoring tool will be used most effectively when combined with suitable professional development in inquiry science and data analysis. In our research in the coming year we will explore these hypotheses with a small group of teachers who will use CLEO under a variety of circumstances.

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Web URLs

EnergyNet

http://teaparty.terc.edu/comweb/energy/energy.html

Students in Illinois conduct a complete energy audit of their school building, measuring:

measuring electricity and gas consumption
heating and air conditioning costs
the size of the building envelope

Classroom FeederWatch

http://teaparty.terc.edu/comweb/cfw/cfw.html

Students count kinds and numbers of different bird species that visit their bird feeder following a precise protocol developed by Cornell Ornithology Lab.

CLEO

http://teaparty.terc.edu

CLEO (Collaborative Learning Environments On-line) is a Web space that makes it possible for anyone with an Internet browser to create a data-rich inquiry project in science or mathematics. Visitors to CLEO can browse the library of projects, participate in a collaborative project, or author a new project of their own. Each CLEO project features a full description of the scientific or mathematical investigation, the complete data set for that investigation, and a discussion of the findings.

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