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The CoVis Collaboratory Notebook: Computer Support for Scientific Inquiry[1]

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1. Introduction

Though one wouldn't know it from the experience of students in high school, the practice of science takes place in a rich social context which is shaped by an increasing amount of communication and collaboration (Kraut, Egido and Galegher, 1990). While high school students' experience of science consists in large part of performing carefully-scripted tasks designed to reproduce known findings, the researcher's world is full of complexities, unknowns, and personalisties, all of which must be dealt with in the course of completing work that generates new knowledge. Given the dramatic difference between these experiences, it should be no surprise that students often leave high school with an incomplete vision of the practice of science.

In an effort to make high school science learning more faithful to scientific practice, the Learning Through Collaborative Visualization (CoVis) project is examining the use of state-of-the-art networking technologies to support collaboration in science education. The six earth and environmental science teachers who have been participating in the first phase of the CoVis project have adopted a project-enhanced pedagogy that emphasizes the role of open-ended inquiry and collaboration in science learning. To support this pedagogy, the project has provided them with a set of tools, adapted from those used by scientists, for students to use in investigating weather and climate-related phenomena (Fishman and D'Amico 1994; Gordin, Polman and Pea, in press), and a variety of means to share research efforts with one another and with scientists across the Internet who specialize in studying these phenomena. The technologies for communication and collaboration that CoVis provides include desktop video teleconferencing, common Internet tools such as e-mail, news, ftp, gopher, and world-wide web, and a custom-built collaborative inquiry environment called the Collaboratory Notebook (Edelson & O'Neill 1993; O'Neill & Gomez 1994) .

The Collaboratory Notebook is a shared, hypermedia database that supports communication and collaboration both locally and over the Internet. In this paper, we describe the role the Notebook has played in supporting collaborative scientific inquiry among the students, teachers and scientists of CoVis' distributed community over the first few months of its use. To establish a context for this work, we provide a brief characterization of collaboration as it has been documented among scientists and industry researchers. Taking scientists as a starting point, we proceed to a description of the types of collaboration that we have attempted to foster in the CoVis project. We then describe the Collaboratory Notebook and its design as a support for collaborative inquiry among the students, teachers and researchers in a distributed learning community. The final two sections are devoted to a discussion of our early experiences with the use of the

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Collaboratory Notebook to support high school science learning. The first of these sections presents four examples of the use of the Notebook to support collaboration. The second focuses on the challenges of integrating this technology and the open-ended science learning it is designed to support into classroom practice.

2. Collaboration in Science

Studies by Kraut, Egido and Galegher (1990) and Kraut, Galegher and Egido (1988) suggest that research collaboration is on the rise among scientists. In their surveys and similar ones by Hagstrom (1965), researchers indicated that they felt collaboration made the creative process more enjoyable, improved the products of their work through a synthesis of ideas, and provided a good motivation to maintain relationships that were threatened by distance. Kraut, Egido and Galegher (1990) go on to document the dramatic influence that physical proximity and the cost of communication have on the formation and maintenance of working relationships among scientists. In brief, they found that collaborators with ample opportunities for informal communication are able to easily assess personal compatibility, check the progress of work efforts, alert partners to relatively minor problems, and to enforce feelings of guilt (Kraut, Egido and Galegher 1990, p. 162).

In another analysis of scientists' collaborations, Fish et al. (1993) developed a set of fourteen categories of activity to characterize the communication which takes place in the course of collaboration:

1. Check project status
2. Stay in touch
3. Exchange time-sensitive information
4. Ask question
5. Exchange information
6. Schedule meetings
7. Make commitments
8. Make decisions
9. Generate ideas
10. Negotiate or bargain
11. Resolve disagreements
12. Get to know someone
13. Explain difficult concepts
14. Exchange confidential information

These categories include elements of collaboration that often require face-to-face or synchronous communication, however one of the goals of developing computer support for collaboration among students is to facilitate as many of these activities as possible.[2] In a more vivid description of collaboration, Kraut, Egido and Galegher (1990), describe the sort of activities that characterize informal planning meetings among researchers:

> Most often, the participants do not prepare for these meetings in any formal sense. There is little reliance on prewritten documents or diagrams as a basis for the discussion; instead,

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[2]These categories were developed to be used in studies in which users rated the suitability of different media (i.e. desktop video conferencing, face-to-face, phone, and documents) for conducting these activities. These categories are being used in similar evaluations of the media available to participants in the CoVis project.

> collaborators seem to value the opportunity for spontaneous, informal and unstructured exchange of ideas. The participants talk, argue, interrupt, write equations, draw sketches, and modify both their own and their partners’ work. Participants may take notes in order to have a record of important observations or issues that arise in the conversation or to remind themselves of things to do—articles to read, people to contact, purchases to make—but there is usually no explicit effort to make a formal record of the proceedings (Kraut, Egido and Galegher 1990, p. 162)

The key characteristic of this description is the informal nature of the communication and the lack of structure required by its participants. A goal of the Collaboratory Notebook is to provide support for students as they participate in similar forms of collaboration. However, high school students do not possess the experience in either open-ended inquiry or collaboration that scientists have. Therefore, an environment for collaboration among students must provide some structural support. Scientists’ skillful opportunistic use of informal communication reflects the fact that they have undergone a long process of enculturation into a community of scientific practice. Their exchanges seem effortless simply because they have no need to establish any explicit protocols with respect to the complex activities mentioned above: through their enculturation into a community of researchers, they have come to share a complex set of values with respect to the work that they do, and the importance of certain intermediate products within it (sketches, articles, to do lists, etc.).

3. Collaboration in Science Learning

The approach to science learning that CoVis intends to support is based on the recognition that scientists working within a discipline constitute a community of practice (Lave & Wenger 1991), and that students’ experience of science should involve them as legitimate peripheral participants in that practice (D’Amico et al., in preparation, provides a study of the atmospheric sciences as a community of practice). However, in order for students to participate in authentic scientific practice, they require many things. For a start, they must have access to the same sorts of tools used by scientists, and to scientists themselves who can serve as mentors and research partners. Then, they must become engaged in activities that will allow them to undergo the complex process of enculturation into the community of practice.

To meet these needs, the CoVis project has provided students with a set of scientific visualization tools that allow them to investigate the same questions in the same style as atmospheric researchers, and assembled a community of participants that includes researchers in the atmospheric scientists at the University of Illinois in Urbana-Champaign, and informal science educators at the Exploratorium museum in San Francisco. This small community is designed to provide a model for much larger scale communities in the future.

In assembling this community, we have aimed to generate two primary forms of collaboration. One form takes place between students and their peers. In this model, students make use of distributed expertise and a common pool of labor to achieve a research goal. In relying on one another to complete their work, they encourage each other to articulate their incomplete knowledge and to clarify and extend their contributions. A very different form of collaboration takes place between students and scientists or teachers. In this form of collaboration, the adults act as mentors, overseeing students work and providing the benefit of their guidance and experience.

The tools that comprise the CoVis communication and collaboration environment are designed to support different needs in relation to these forms of collaboration. The research described above indicated the importance of proximity to effective collaboration. Fish et al. (1993) have explored the potential value of videoconferencing for providing some of the benefits ordinarily associated with working in close proximity. Used appropriately, this technology can serve some of the functions that direct face-to-face conversation serves, and allows for the sort of informal contact and communication that characterize working relationships among collaborators who work in close proximity. Desktop video teleconferencing is included in the CoVis classroom environment to learn whether it can play the same role that Fish et al. (1993) observed in a scientific community.

For the elements of collaboration that benefit from face-to-face communication, videoconferencing may be a partial substitute for proximity. However, other important aspects of collaboration, particularly for those who are not yet competent researchers, include the ability to construct shared artifacts, to reflect upon the process of their work, and to maintain a permanent record of the inquiry process that can be passed on to posterity. It is these aspects of collaboration, which professional researchers manage for themselves, that the Collaboratory Notebook is designed to support.

4. The Design of the Collaboratory Notebook

The Collaboratory Notebook is a medium for students to record their thoughts and actions as they perform scientific inquiry. Many of its features have benefited from other research on other communal databases for learning such as CSILE (Scardamalia and Bereiter 1991; Scardamalia, Bereiter et al. 1989), INQUIRE (Bruner 1990), and GroupWrite (Schank and Osgood 1993). However, the Collaboratory Notebook has many unique features of its own which arise from its purpose in serving large distributed community.

The Notebook's interface is built loosely on the metaphor of a library; with bookshelves, notebooks and pages being the primary interface elements. When a student or teacher logs on, a bookshelf displays all of the notebooks to which that individual has access (Figure 1).

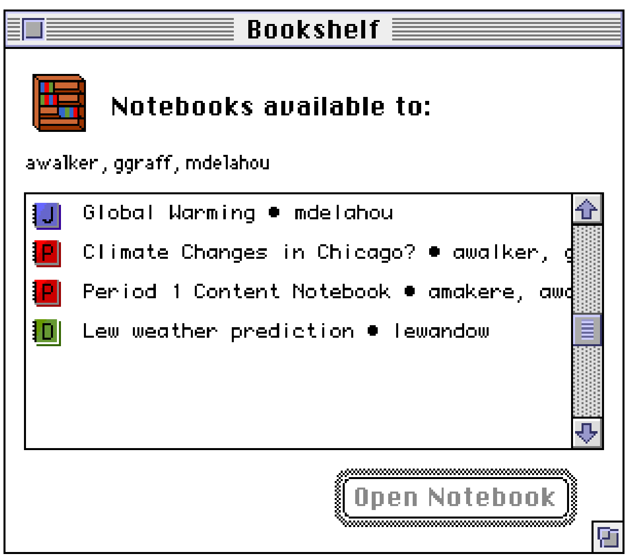

Figure 1. A Bookshelf. The color and letter on the icons at left indicate whether the notebook is a journal (J), project notebook (P) or discussion (D).

Notebook users can create three different types of notebooks. These are:

Private Journals. A private journal can only be read or modified by its single owner.
Project notebooks. A project notebook is shared by a group of individuals, all of whom may read or modify it. A project notebook provides a location for a group of students, teachers and scientists to share inquiry.
Discussions. A discussion is open to any member of a community. Discussion notebooks provide a medium for public dialogue among students, teachers, and scientists on a topic of mutual interest.

All of the notebooks described above share the same structure. A notebook consists of a title page with a brief description of the notebook's purpose, a table of contents, and any number of content pages. The table of contents for a notebook displays the notebook's title, a list of its authors, and an overview of its pages, including their types, titles and relational structure. The table of contents for a Project notebook is shown in Figure 2.

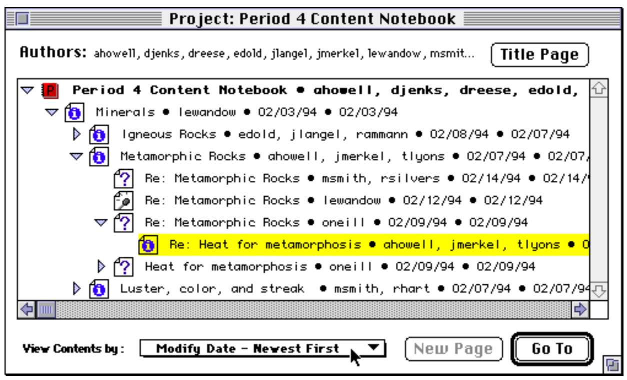

Figure 2. The table of contents for a whole-class project notebook.

Each page in a notebook has a type (indicated by its icon), a title, and a set of authors. Pages may be authored by individuals, or by a group of people working together at the same time. The types given to pages by their authors provide both a description of their contents, and of their relationship to other pages. The page types available to choose from in the current version of the software are:

Information. An information page can describe an experience, or offer some knowledge that is seen as useful to the investigation.
Commentary. A commentary page offers a view on what has been written in another page, or suggests a direction for future investigation or discussion. Commentaries are useful for feedback and guidance from instructors.
Question. A question page can be used to record one or many questions. These could include a response to the contents of another page or central research questions.
Conjecture. A conjecture page is used to record hypothesized answers to questions in a notebook.
Evidence for. An evidence-for page is used to provide justification for a conjecture. Evidence might take the form of scientific visualizations, information gathered from outside sources, or logical arguments.

Evidence against. An evidence-against page contains evidence that contradicts a conjecture.
Plan. A plan page records a plan for answering a question or verifying a conjecture.
Step in plan. A step in plan is a page for recording the process and results of carrying out one step in a plan.

Notebooks are created by linking pages together in accordance with the structure of an inquiry.

4.1 Browsing and Authoring Pages in a Notebook

Because the Collaboratory Notebook is intended for both reading and writing in the course of an investigation, it has been designed to support both activities equally well. However, since these activities play quite different roles in the process of enculturation we wish to engender, the software shapes them quite differently. Figure 3 shows a notebook page as it appears when it is being read.

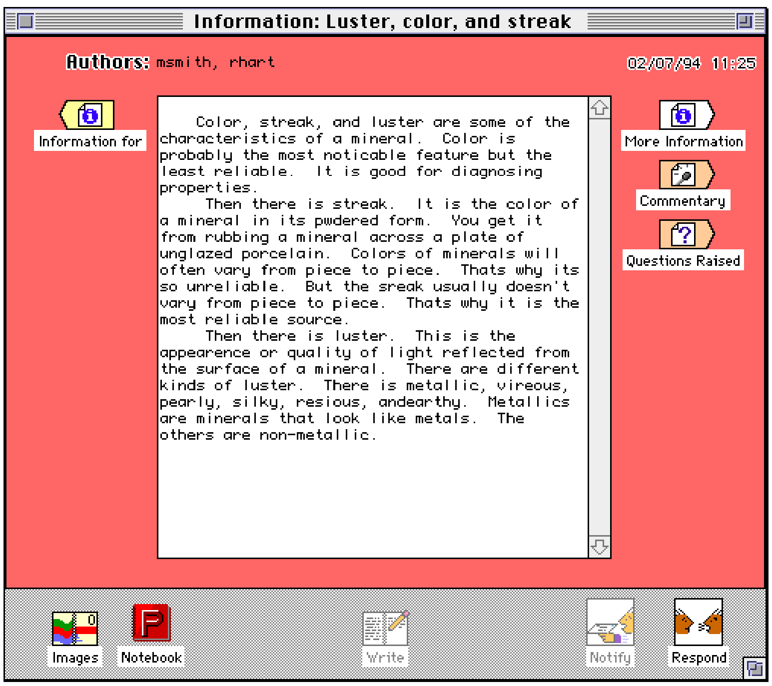

Figure 3. A question page from a project notebook.

The top of a notebook browsing window displays its title, its authors' names, and the dates it was created and last modified. On the right and left sides of the window are arrow-shaped buttons representing links that connect the page to others. On the left is an icon representing links *to* the displayed page from other pages that inspired it, and on the right are icons representing links *from* the displayed page to other responses. In other words, the Collaboratory Notebook maintains the convention that links between pages come from the left and go to the right.

When a user clicks on one of the arrow buttons with the mouse, she is presented with a list of pages of one particular type that are linked to the current page. For instance, if the user clicks the "questions raised" button, she sees a window displaying a list of pages containing questions in response to the page she is reading. She can then select any one of these questions to view, or can respond with a new question of her own.

To inform a reader, the background color of each arrow button changes to indicate how many pages of that type are linked to the current one. For example, if a question page has no conjectures attached to it, the background of the conjectures icon will be white. Once a user attaches a conjecture to this page, the background of the conjectures icon will change to a light shade of pink. As more conjectures are added, the color changes to increasingly dark shades of red.

Users are also able to store graphic images in a notebook. At the lower-left of every notebook page is an icon labeled "Images." By clicking on that button, users can either see the images that have been attached to that page or attach new images. Like the buttons that indicate links to other pages, the Images icon changes appearance to indicate the number of pages that have been attached. In coming weeks, a new feature will be added that will allow users to attach arbitrary Macintosh documents to any Notebook page. When a user chooses to view an attached document, the application that created the document will be launched and the document will be loaded in.

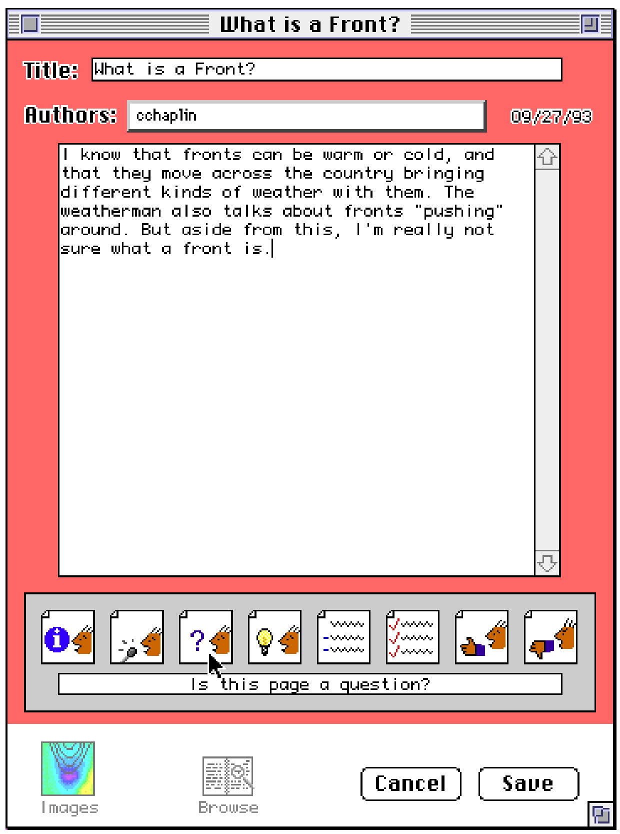

Figure 4. A question page being edited. The user classifies the page by clicking one of the icons in the lower section of the window.

When a page is being created or modified, it appears in a different form (Figure 4). The band of icon buttons near the bottom of the page writing window provides authors with options for classifying the page. This classification may be changed repeatedly as the authors' sense of what they have written and its place in the inquiry evolves; however the software requires that the user select a type for each page before saving it.

4.2 A Supporting Structure for Collaborative Inquiry

The particular outgoing link types that a page may have are determined by the type of that page, according to a process model of inquiry. To give an example of how this model applies, a Conjecture page may take Evidence-for and Evidence-against pages as responses, but a Plan page may not. All pages have links for questions raised, more information, and commentary. These are known as *universal links*.

The page types and response palettes supported in the notebook have been chosen to help students structure their inquiry by focusing on small intermediate products and the relationships among the steps in the inquiry process. Employing a small, fixed set of page and link types offers two significant advantages. First, it provides students with a framework for conducting a dialogue which is tailored to the task at hand. Second, it helps to encourage consistent conventions of use across the larger community which CoVis supports.

The structure of the notebook helps students to structure their inquiry through its interface. When a student has created a notebook entry from scratch, the Notebook prompts her to characterize it. Is it a question, a comment, information, a conjecture, or a plan? When a student reads a page, the interface reminds her of ways that she might choose respond to it. For example, if she's reading a conjecture, the display of that conjecture reminds her that in addition to raising questions, commenting, or adding information, she might respond by providing evidence for or against it. Similarly, when she's reading a question, she is reminded that she could propose a conjecture about that question or a plan to research an answer. Table 1 shows the response palette available from three types of notebook pages.

Page Type	Available Follow-ups
Question	More Information, Questions Raised, Commentary, Conjecture, Plan
Conjecture	More Information, Questions Raised, Commentary, Plans, Evidence For, Evidence Against
Plan	More Information, Questions Raised, Commentary, Step in Plan

Figure 5. Available responses for Questions, Conjecture and Plan pages.

The utility of this scheme is that by creating a number of pages, each containing only a small amount of writing, a student can create a large, complex investigation in a stepwise fashion that makes the relations of the individual parts explicit. The collaborative nature of the work supported by the notebook means that participants can reflect directly upon each part, encouraging the authors to clarify or extend their contributions.

A second reason for using a small, fixed set of page and link types is that they lead to helpful conventions of use for the tool. These conventions will enable our large community of users to develop expectations about the contributions of others. In the few months in which the Collaboratory Notebook has been in use, we have already seen sets of conventions arise for the revision of successive drafts of students' project proposals, the organization of knowledge gained by students from interviews with experts, and the sharing of responsibility between teachers and graduate students for mentoring groups of students. Within these conventions, the small number of page types makes the selection of an appropriate type for a page nearly automatic; and the fact that the set of types is fixed allows students, teachers and scientists to develop expectations that are useful in reading the work of others. If students were free to create their own page and link types, one student reading another's work would not be able to form reliable expectations about the semantics of any particular link or page type.

4.3 Integration of the Notebook with Scientific Visualization

Scientific visualization tools are an important element of the CoVis software suite. To assist students in recording their own inquiries and sharing in the inquiries of others, the Collaboratory Notebook is tightly integrated with these visualization tools . Each of the tools generates an automatic log of users' actions. Using standard Macintosh cut and paste operations, students can place sections of these activity logs into appropriate pages in their notebooks and elaborate upon these terse computer-generated logs with more extensive descriptions of the context in which those actions were taken, their purpose and results. In addition, students may attach images created by the visualization software or a painting program to any notebook page. These images can be titled and annotated to reflect their role in an investigation.

4.4 Working Together in the Notebook

The Collaboratory Notebook has been designed to support both synchronous and asynchronous collaboration. Shared project notebooks and discussions allow for participants anywhere on the Internet to contribute to an inquiry. Authors can be added to and removed from a notebook at any time to accommodate the dynamic nature of collaborative project groups. Within the classroom, several individuals can be logged into the notebook at a time, so that students can work together simultaneously at one computer. Any pages that are created in a multi-user session bear the names of all the users as authors. Also, since the CoVis software environment allows two users at separate computers to share one screen[3], authors at different locations can work as if they were sitting at the same keyboard, regardless of the distance that separates them.

5. Four Collaboration Efforts in the Notebook

The Collaboratory Notebook has been available for use in two high schools for five months at the time of this writing. During this time, four of the six teachers participating in the project have used it in a variety of ways. To date, 118 students in 6 classes have created 59 notebooks containing a total of 352 pages. In this limited time, we have seen

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[3] Screen-sharing in the CoVis environment is supported by Timbuktu and Timbuktu Pro from Farallon Computing.

several very encouraging uses of the Notebook to support collaboration, four of which are described in this section. We have also experienced challenges that have made it difficult for teachers to integrate the Collaboratory Notebook into classroom practice as extensively as we had hoped. These difficulties are described in the following section.

5.1 Parallel Investigations: The Weather Prediction Discussion

The scientific visualization software available in the CoVis software suite offers teachers and students the ability to get up-to-the-hour weather data. Using this data, students can track weather, observe the cycle of storms from genesis through dissipation, and make weather predictions. One teacher chose to use the Collaboratory Notebook to provide a structure for a weather prediction activity in a way that allowed students to compare their predictions with those of others. The teacher initiated the activity by creating a discussion notebook that could be accessed by all the students in his class. At the top level of that notebook, over a period of days, he entered a series of question pages asking his students to predict the weather for a given date several days in advance. For example, on December 6, he created the following page[4]:

> **Question: Predictions for 12/9**
> **Author: *Teacher***
> Predict the weather for Thursday 12/9. Do not use anybody's else's prediction. Base you prediction on WX maps, satellite photos and local data only.

During the next two days, seven groups of students entered predictions. Two of these appear below:

> **Conjecture: *Student1* and *Student2* weather prediction 12/9**
> **Author: *Student1, Student2***
> We predict that the weather in Chicago on 12/9/93 will have light rain and some snow flurries. The temperature will drop to the upper 20's lower 30's, and it will be very windy. The pressure will rise and the sky will be overcast. The nearby coldfront will pass near us but will not come in contact with Chicago. The dewpoint will drop. We say it because we looked at the maps and at the wind direction, speed, dewpoint, temp, etc etc. By looking at these points on the maps, we could tell (hopefully) what the weather would be like.

> **Information: Re:weather prediction**
> **Author: *Student3, Student4***
> *Student3* and I (*Student4*) predict that there will be 35%-40% chance of rain on Thursday. The temp will be in the lower 40s to upper 30s.

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[4]All notebook entries in this section were copied directly from the central notebook database without any corrections of spelling or grammar. All names have been replaced with appropriate anonymous identifiers.

```
The wind will be coming from the west. Look at the
wxmap in my public folder5 (Student4) for what we
think is going to be where the fronts and storms
are going to be.
```

Following this activity, students had the opportunity to compare their predictions against each others and against the actual weather on December 6. By examining each others' predictions and the processes by which they made these predictions, they had the opportunity to improve their understanding of the processes underlying the weather. While this activity was designed to use the Notebook to provide an opportunity for groups to compare results, it was not planned as a means to provide cross-group collaboration. However, in the process of making their prediction, one group of students learned something that they felt would be of interest to the other groups as well. They used the notebook as a means to share this new knowledge. These students attached the following page as "more information" to the teacher's original request for weather predictions:

```
Information:  Hint for weather predictions
Author:  Student5, Student6
Hint:
It is useful to use the upper-air information with
windbarbs in order to see the wind speed.  Since
fronts move with the wind in the upper atmosphere
you should look at these maps as well as the
surface map.
```

In this use of the Collaboratory Notebook, students were able to conduct their investigations in an environment that integrates scientific visualization with a medium for recording conclusions. They were then able to share and compare their results within the Notebook and event to provide each other with helpful hints.

5.2 Independent Investigations with Telementoring

In this use of the Collaboratory Notebook, the teacher had his students read an article about climate trends across time that may indicate the global climate is warming. To investigate this phenomenon, he had groups of students use one of the scientific visualization tools developed as part of the CoVis project to track temperatures in key cities over a twenty year period. The student groups each created a graph of the temperatures and placed them in a project notebook. They then discussed their analyses of the graphs in the notebook. The following is a plan entered by a group of students investigating Rome, Italy:

```
Plan: Analysis for graph of Rome
Authors: Students
The question that has been posed upon our group is
weather or not the temperatures of December are
rising.  Our group has decided to get all the
temperatures for as meny years as we can so we have
```

[5]This Notebook activity was conducted before students were able to store graphics within a notebook. The are currently able to attach graphics to any Notebook page.

```
a larger range to look over.  Our major form of
information will be the climate maps on the
notebook and visualizers.  Once we have about 25
years of temperatures and have entered them onto a
spreadsheet it will be easy to make a computerized
gragh of the data that we have come across.  One
look at the gragh will prove that the temperatures
of December are rising.  The gragh should be all
the proof that we need to confirm our theories.
```

The graph generated by this group appears in Figure 6.

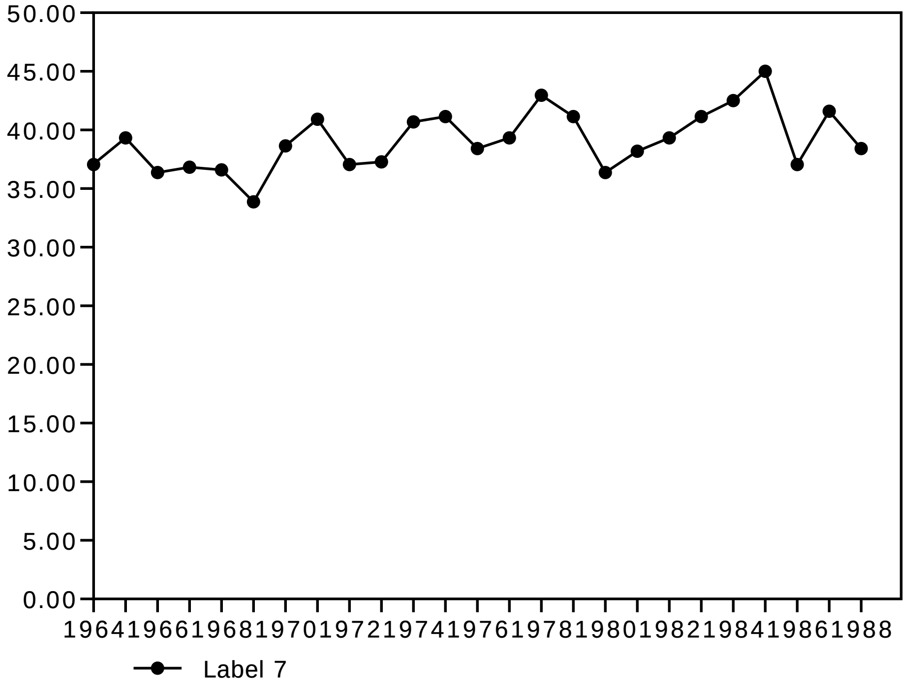

Figure 6. A graph generated by students showing December temperatures in Rome over a 24 year period. The students' caption for the graph read, "This graph is a description of the temperatures in Rome over a twenty-five year period. The equation of this line is, y=.17x + -301.04 and the r value is 0.01 which is not very good considering that the best line has an r value of one."

As part of this activity, collaborators from the Department of Atmospheric Sciences at the University of Illinois at Urbana-Champaign and the Exploratorium science museum in San Francisco participated in these notebooks. The teacher asked these "mentors" to monitor the Notebooks periodically and asking questions intended to help students to refine their investigations. The following interchange from the group studying Rome indicates one form that this type of collaboration took:

Commentary: Commentry on graph of Rome
Author: ***Students***

It is very clear that the overal temperature of Rome are rising. The equation of the line also agrees with this theory. There is no point in the graph that temperature is noticably decreacing. For example if you cut off the last few years or the first few years the outcome would stay the same. When yearly temperatures are at their peeks they do not stay there for more that two years befor decresing to a low. The same is evident here, the tempersture does not stay at a low for more than a year before increasing. As our group looked at other graphs in comperison to our own it seemed other graphs looked the same. We would like to find the reason for this effect.

Question: Re: Commentry on graph of Rome
Author: *Meteorology graduate student from UIUC*
That's a good question, why does that trend occur? My question is, how do you intend to answer it? What sort of things would you look at? Maybe the best place to start is, from off the top of your head, without having done any research, why do you think your graph of Rome looked like this:

"When yearly temperatures are at their peeks they do not stay there for more that two years befor decresing to a low. The same is evident here, the tempersture does not stay at a low for more than a year before increasing. As our group looked at other graphs in comperison to our own it seemed other graphs looked the same. We would like to find the reason for this effect."

Conjecture: Re: Re: Commentry on graph of Rome
Author: *Students*
The only possible reason that we could think of is that this is natures way of controlling the tempertures on Earth. It is sort of like the eco system everything balences out. The reason that the average temperature is rising in December is because humans are messing up the Earth just like they are messing up everything else. In our opinion is that if the earth were not populated by humans the everage temperature would not rise at all it would just fluxuate. These are just our personal ideas about our question, we did not reaserch any of what we have said in this paragraph.

By conducting this open-ended activity in the Collaboratory Notebook, students were able to take advantage of the notebook's structure for linking questions, conjectures, and plans, as well as integrated computer-based tools for inquiry and guidance provided by remote, scientist mentors.

5.3 Remote Collaboration in Planning: The Harm's Woods Notebook

On April 20, 1994, the twelve classes participating in the first phase of the CoVis project will conduct a series of data-gathering activities at a Forest Preserve called Harm's Wood in the Chicago area. Each of the classes will be responsible for measuring specific items of interest, such as water quality, soil composition, and ground cover. These measurements will be combined to construct an overall picture of the health of the Harm's Wood environment. These data gathering and analysis activities will require a substantial amount of coordination and collaboration across classes and across schools, and have involved a significant amount of planning on the parts of the teachers. These planning activities have been conducted at meetings, by electronic mail, and in the Collaboratory Notebook. While this activity involves teachers not students, it may serve as a model for similar student activities in the future. The Notebook has been used both as a way to record and summarize discussions that have taken place elsewhere and as a medium for discussion itself. For example, the following page records an important early meeting in the planning process:

Information: Proposed Actvities from 2/25 Meeting
Authors: *Teacher1*

```
"Here is the activity list from Friday 2/25:
From "Global Lab"
-CO2 Monitoring
-UV measurement
-Mapping (confirmation of existing maps and aerial
photos
-Actual rainfall?
-Vegetation cover
-Soil pH
-Rain pH
-Light intensity
-Soil characteristics
-Weather conditions
-Air temperature
-Water Quality
-Particulate
-noise/sound
-odor
-traffic
-Air Quality (sulfur,nitrogen,lead)
-Fish (analyze-outside lab)
-biodiversity
-Video/photography documentation
-Stream morphology"
```

A significant portion of the pages in this notebook are devoted to the sharing among the teachers of ideas about how they would like the data-gathering day to go. This discussion was initiated by the following page entered by a graduate student who is helping to coordinate the event:

Question: "What will the different classes do?"
Authors: *grad student*
As part of our planning, we discussed the need for each teacher to determine what questions and data their class will be concerned with during the day in the field and in analysis afterward.

Once everyone determines what they are most interested in, it seemed like cross-class collaborations could be built up, and plans for data collection could be determined.

So, what are you and/or your students interested in doing?

More to come ...

Two responses to that page follow:

Conjecture: "Re:*Teacher2*'s STS Class"
Authors: *Teacher2*
I would like my students to look at comparing Harm's woods to wilderness in some way - to see how enclosed nature preserves compare to nature.

To do this, I would like them to do some research into measuring some criteria of wilderness - ranges of water and air purity in particular, and then compare those to the levels measured by other classes.

Also, we might be involved in a study of litter (to be coordinated with other classes) and noise pollution. Aside from that, I would like to see some subjective descriptions of thier experience in the woods compared to their normal urban experiences."

Commentary: Research Categories
Authors: *Teacher3*
Introducing this idea to my classes, we came up with 5 broad areas that could be looked into:

- Water
- Air
- Soil
- Human use
- Biology

I plan to work with my classes to see where their interest lie and let their interest divide them into groups. I already have someone interested in researching what plants (trees mostly) should be found there and which ones are "invaders". (I do not want to get too far into the biology)

On another occasion, a teacher initiated a similar thread with the following entry:

Conjecture: What activities will we pursue?
Authors: *Teacher2*
I see the trip as having two components. The first is work that leads to a joint effort with some concrete product. This might be a document and a data base on the fileserver that will be the basis of future projects in following years. The theme for this collaborative work so far looks like "What is the health of Harm's Woods as a nature preserve". Or something like that.

The second purpose has to do with the specific curriculum each teacher wants to reinforce, and may include activities that have nothing to do with the collaborative product, but will take advantage of being outdoors.

In other words, we need to determine what we want to do together, and what we need to do separately."

This page was followed up by a number of pages, two of which follow.

Question: What factors have to do with "health" of the preserve?
Authors: *Grad Student*
I think the two components that *Teacher2* mentioned are about right. One of the things that struck me, though, is that some of the variables and data that simply *describe* the region are important to a more complete discussion of its health. I'm thinking of soil related info and vegetation info.

What do others think?

Commentary: General Idea for the day
Authors: *Teacher3*
I see several different parts to the day. I am getting more interested in the collaboration component to our courses so I would very much like to work with another class for part of the day. Together we could select several parameters to measure for each sub group and have them do the tests. After we get back, the classes would have to excahnge the data (via dn net) before actualy analysis could occur.

> I do plan to spend part of the day (preferable the last part) with either a personaly-guided tour or a worksheet tour showing the students certain locations, asking questions and observing Earth science at work.
>
> Depending on how the data collection was set up, my classes may need to collect some additional data that we decide on over the test area as well.

In addition to the teachers and the graduate student who were participating in this discussion, there were two outside "consultants" with considerable experience in working with teachers who are adopting a project-centered approach to science learning. They also contributed to this discussion taking place among teachers in the Chicago area from their workplaces in Cambridge, MA. For example, they encouraged the teachers to be clear about their objectives in the following section from a Notebook page:

> **Information: From *Consultant1* and *Consultant2***
> **Authors: *Teacher3*[6]**
> Once again, you have sent us your snow! We are suppose to have 10 to 15 inches by morning. The skiing should be good this weekend. *Consultant2* and I had indicated that we would contribute ideas about aims for the Harms Wood project and a file of assessment techniques to monitor progress in regard to these aims. We are sending you some beginning thoughts, first focusing on aims.
>
> In our joint efforts to identify aims it may be helpful to consider: Why we are doing the project and what we are hoping will come out of the project for students. Writing a paragraph that simply states our individual ideas about what we hope students will gain may be a useful beginning place. *Consultant2* and I have taken a shot at this and our paragraph follows:
>
> Why do this project? What will students gain? Students will gain a different level of awareness about the "health" of a local environment. They will become familiar with environmental factors, relationships, and cycles. They will learn new ways of approaching problems, recognize the strengths of collaboration, and work beyond the limitations of school walls. They will gain skill in using

[6]For technical reasons, at the time this page was entered, the consultants were unable to add pages to the notebook themselves. Therefore, this page was entered by sending it to a teacher via e-mail who entered it for them. Subsequently they got full access to the Notebook and entered their pages themselves.

> first-hand information as well as second-hand information to build understandings. First-hand experiences at Harm's Wood will give them a concrete basis from which to build sophisticated abstract understandings. They will witness the potential power of technology to support data gathering, representation and interpretation and to support the sharing and negotiation of ideas.
>
> We believe that several of the continuing challenges that were expressed at the February meeting may begin to be addressed through the identification of aims, in particular, how to establish clear and attainable goals, how to incorporate content into student projects, and how to meet the needs of different learners....

In this case, teachers were able to augment their planning activities conducted in-person and via electronic mail with a discussion in the Collaboratory Notebook. Because it is networked and supports asynchronous communication, the teachers were able to participate in the discussion when they could fit it into their daily schedules. It is our hope that this experience with the Notebook will encourage the teachers to have their students to use it in a similar way to support the cross-school collaborative investigations that will occur following the data-gathering activities at Harm's Wood later this spring.

5.4 Maintaining a Shared Progress Record: The HVAC Notebook

In this fourth example, the Notebook was used in a way that was not anticipated by its designers. In this class, the students were investigating the infrastructure of their school and were divided into groups that studied different systems in their building e.g., electrical, communications, and heating, ventilation, and air conditioning (HVAC). Each group toured the school and interviewed the personnel who were responsible for operating and maintaining the system they were investigating. In the case described here, the students were investigating the HVAC system and used the Notebook as a medium for recording their interviews with building personnel. In fact, they were able to exploit the structure of the Notebook for this purpose by using question pages to record their questions and information pages to record subjects' responses.

The teacher of this particular class works very hard to get project groups to work efficiently by dividing the work among individuals. For example, in the HVAC group, different students had responsibility for conducting interviews, documenting the infrastructure through photographs, and recording interviews in the Notebook. The students all worked together to compose the questions for the interviews. The Collaboratory Notebook, in this project, provided a mechanism for recording this distributed process through a central repository for recording interviews. In addition, its structure enabled students to record their interviews in a way that reflected the conceptual flow of questions and answers. The hypermedia interface allows students to link questions and answers to each other according to their conceptual relationships. These conceptual relationships may or may not reflect the chronological order in which the questions were asked. Through the process of recording these questions and answers in the Notebook students were able to identify new questions for subsequent interviews based on the gaps in their knowledge revealed in the recording process.

The following illustrates the students’ uses of the Notebook to record the questions and answers from their interviews. These different pages were entered by different students in order to build a single, shared database of their investigations.

The following question initiated a series of pages:

Question: What in power plant runs on gas?
Authors: *Student1, Student2*
What equipment in the power plant runs on natural gas?"

The following page was linked to the previous one by a “More Information” link:

Information: Three boilers
Authors: *Student1, Student2*
The three boilers and three generators run on the gas. Boilers produce-55,000lbs./hr. Generators produce- 800kw/hr."

This page in turn was followed by another “More Information” link to the following page:

Information: How they use the gas
Authors: *Student1*
The generators are gas fired and the boilers will modulate depending on the steam load. "

Some time later, the following question appears:

Question: Where is the gas coming from ?
Authors: *Student1*
Where is the gas coming from that the highschool uses?"

The preceding page is linked to the following one by another “More Information” link:

Information: "The gas comes from..."
Authors: *Student1*
There are two maines. One comes in the front of the building at the main office and the other is across the street in the boiler room which is for the boilers and co-generators."

In the course of their one-month investigation, the four students entered seventy-nine notebook pages covering topics as far-ranging as the cost of heating the building, where the waste goes, how the air conditioning works, why the radiators bang, and what the cooling towers do. Most of the pages were brief like the ones above, but the total amount of information was quite comprehensive. Furthermore, it was organized in a structure that the students felt reflected the relationship among the ideas they were investigating. It is our belief that the structure provided by the Notebook helps students to better structure their understanding as they explicitly record their inquiries in the process of conducting them. In the case of this use of the Notebook, it provided the students with an opportunity to consolidate the work that they had done in previous interviews in order to plan subsequent ones. In this way, it played a role in helping them to coordinate their group’s activities.

5.5 Observations about Collaboration in the Notebook

As we said in the introduction to this section, these collaboration efforts represent early uses of the Collaboratory Notebook. However, it is possible to draw some generalizations from these examples. First, in every example presented here, the Collaboratory Notebook was only one mechanism for the communication that took place in the course of these collaborations. Except for the participation by “telementors” in the notebook described in Section 4.3, the collaborators knew each other before initiating the collaboration and had the opportunity to speak to each other during the time that they were working together using the Notebook. While the Notebook holds some promise for collaborations in which the collaborators are at a distance with no other means of communications, it is much more likely to be useful in situations such as those described here, in which the Notebook provides an organized, persistent record of the ideas that have been exchanged, and the work that has been done.

To justify its use, the Collaboratory Notebook must provide benefits that are not provided by the current generation of tools for communication and collaboration. The four examples cited here show the possibilities of the Notebook to provide these benefits if it is well integrated into an environment of open-ended inquiry. In the Weather Prediction Discussion from Section 4.1, the students were able to use the Notebook as an on-line logging facility as they performed their weather predictions. They could move quickly and easily between the meteorology tools that they used to generate their predictions and the Notebook in which they recorded them. However, the Notebook improves upon any ordinary environment for logging activities because the predictions immediately went into a shared database that enabled students to compare their predictions and draw make generalizations from them. The Notebook also provided the teacher with an opportunity to monitor student progress at all times without ever requiring students to hand anything in.

In the investigation of climate change described in Section 4.2, the students had the opportunity to share the results of their investigations and their conjectures in an environment that is integrated with the investigative tools. The nature of this discussion bears a resemblance to those that have been described in the CSILE environment (Scardamalia and Bereiter 1991). Cohen (1994) has presented evidence that even when they are working face to face, students’ knowledge construction activities are more productive when they are conducted in an environment that encourages them to articulate and structure those ideas. In this instance, the networked nature of the Collaboratory Notebook also allowed scientist mentors to contribute to these knowledge building dialogues by monitoring student entries and linking guiding questions where they were appropriate.

In the Harm’s Woods Planning Discussion described in Section 4.3, the teachers were able to use the notebook to structure and organize their planning as they collaborated from remote locations. While the teachers had the opportunity to meet in person twice during the time this Notebook was used for the planning process (The planning process is still ongoing at the time of this writing.), a significant amount of ideas were shared in the Notebook independent of any face-to-face or other discussions. In this case, the Notebook provided a private, shared space for discussion. Clearly, this discussion could have been conducted via electronic mail or other conferencing software. The goal of the Notebook is to improve upon such available communication mechanisms through its structure and user-interface. However, it is unclear how one could determine the degree to which the Collaboratory Notebook’s structure and interface might have enhanced or limited this collaboration, as compared with another medium.

Finally, in the HVAC notebook in Section 4.4, students used the notebook to produce a shared record of their inquiry, in a collaboration in which the tasks were divided among group members. In the course of recording their interviews in the Notebook's structured environment, they were able to identify areas that required further investigation.

In the four example uses of the Collaboratory Notebook presented here, students and teachers benefited both from the ability of the Notebook to support remote collaboration and from the structure it provides for recording the inquiry process. Remote collaboration in these notebooks took the form of both peer-to-peer collaboration and mentoring by teachers and research scientists. The structure of the Notebook was used to scaffold a range of open-ended investigations by students.

6. Challenges for the Collaboratory Notebook

The Collaboratory Notebook has been designed as a support tool for an innovative style of science education. This pedagogy emphasizes learning in the course of open-ended, collaborative investigations or projects. For the Notebook to be successful in supporting this pedagogy, a number of challenges must be overcome. In the introduction to this paper we explained that the central objective of the CoVis project is to make science learning in schools more faithful to the way that science is practiced in the adult research community. In fact, many of the challenges of implementing a project-enhanced approach to science learning, and employing collaboration software such as the Collaboratory Notebook, stem from the dramatic differences between the school environment and the scientific workplace. These challenges to the widespread integration and success of the Notebook can be divided into three categories: obstacles to open-ended science learning, obstacles to providing access to technology, and obstacles to collaboration. Several of these obstacles stem from structural properties of schools and several stem from more traditional attitudes and approaches toward teaching and learning.

6.1 Challenges to Open-Ended Science Learning

The challenges to open-ended science learning are both structural and attitudinal. The primary structural challenge is posed by school schedules The standard 45-minute class period does not enable students to engage in any prolonged theorizing, research, or problem-solving before they must move on to the next class. An environment to support the organization and sharing of open-ended investigation can only begin to show true benefits if students are able to conduct investigations of a depth that require a persistent, organized record of the activity.

The primary attitudinal challenges to open-ended science learning come from traditional attitudes about curricula and assessment. An emphasis on open-ended inquiry generally implies a much greater emphasis on depth of understanding as opposed to breadth. Allowing students to learn by conducting open-ended investigations requires a flexibility that stands in sharp contrast to traditional approaches to curriculum. Most current science programs require teachers to cover a certain breadth of material during the course of the year. The requirement of breadth constrains teachers' freedom to foster open-ended activities, because student project activities frequently expand or contract unpredictably in the amount of time they require. For example, one of the CoVis teachers used the Collaboratory Notebook as a medium for a class-wide knowledge building activity in when the students were covering minerals. Students were divided into groups (e.g. igneous, morpheous, sedimentary) and were responsible for adding information and answering questions posed by other students and outside mentors. At the conclusion of the activity, the teacher complained that the projects that he planned to take a week or two grew into a three or four week affair. While a lot of ideas came out of the simple minerals project that might have been turned into interesting projects, this didn't fit into his curriculum plan. In part, this difficulty comes out of the fact that the teacher is struggling with the thorny issues that accompany his commitment to change his view of pedagogy to emphasize open-ended inquiry, and in part it comes from his school district’s expectations that he will cover a certain range of topics in a prescribed period of time.

Because of the importance of assessment in our school systems, it is typically difficult to separate the issues of curriculum from assessment. One of the heavy pressures that teachers feel for covering the breadth of a curriculum comes from the knowledge that students will typically be evaluated according to measures that typically focus on how broad the coverage of a student’s understanding is, not how deep it is in any particular area. However, assessment faces another challenge for open-ended science learning. Teachers need new techniques for assessing their students’ work that go beyond evaluating students’ mastery of scientific facts. The teachers involved in the CoVis project who are undergoing significant transformation in their approaches to teaching frequently complain that they find it difficult to identify objective criteria that can be consistently applied across large numbers of students. In collaboration with the educational researchers on the CoVis project, these teachers are searching for assessment criteria and techniques that they are comfortable with and that are appropriate for the changes that come with a new emphasis on open-ended activities for science learning. An important role for the Collaboratory Notebook in easing the transition to project-oriented classes will be to give teachers the means with which to monitor students’ progress and concrete evidence with which to satisfy the school system’s need for student assessment. However, the Notebook has not yet been able to fulfill this promise. One reason is the need for new approaches to assessment that would guide teachers in using the work recorded in the Notebook as the basis for assessment, and another is the second obstacle mentioned above, access to technology.

6.2 Challenges to Technology Access

The usefulness of an environment like the Collaboratory Notebook requires access to technology. Computers and networks are nearly ubiquitous in the scientific workplace. Use of electronic mail and Internet resources are integral to the practice of a large percentage of scientists. Schools, however, are very different. Even in a project like CoVis in which the classrooms have become technology-rich by comparison to most schools, the ratio of students to computers at any one time is approximately 4 to 1. This means that students either use computers in groups or they must wait for access. For a tool like the Collaboratory Notebook to really prove its value, students and teachers both must have constant and immediate access to it.

In fact, while the project anticipated the challenges that would be posed by having students’ share computers, we originally overlooked the importance of constant and immediate access for teachers. The placement of computers in classes and in labs was designed to maximize students’ access to them before, after, and during the school day. However, the fact that students were actively using those machines meant that teachers did not have sufficient access to the Notebook in order to monitor the work of their students. In addition, teachers are most accustomed to doing this kind of work at home, in the evenings and on weekends. In response, modifications have been made to the Notebook to allow teachers to take copies of student notebooks home on floppy disks and an attempt has been made to make it fast enough to run via modem over ordinary phone lines.

6.3 Challenges to Collaboration

The third set of obstacles to be overcome are obstacles to collaboration. Collaborative learning among students within a classroom has been an important element of many educational innovations, with considerable success. However, assessment still poses a problem for an environment that emphasizes collaboration because traditional approaches to assessment focus on the individual, not a collaborative group. Assessing an individual students’ contribution to, role in, and development as a result of participation in a collaborative inquiry poses a unique set of challenges above and beyond those associated with project science mentioned above. However, unless assessment takes clear account of a students’ role in collaboration, students have a disincentive to collaborate. Since, part of the potential of the Notebook is that it provides a unique structure to support collaboration, its value in that regard cannot be determined unless it is used in a classroom environment that encourages collaboration.

One of the objectives of the Collaboratory Notebook was to support collaborations among students across the boundaries of classes and schools. In several of the Notebook activities that have taken place so far, collaboration has occurred in the form of students in the same classroom working together and in the form of remote mentors contributing via the network. While there has been an example of teachers at different locations using the Notebook to support a collaboration, there have been no examples involving students. The Collaboratory Notebook offers a new opportunity for these classrooms: to participate in collaborative learning activities that go beyond a single class. While this seems like an obvious benefit, taking advantage of the opportunity requires significant incentives. One incentive, which has been explored by other projects using e-mail or other communications techniques (e.g., Songer 1994) is geographic or cultural diversity. In the first two schools that comprise the CoVis testbed neither geographic or cultural diversity are offered in any important way to the two neighboring schools by the other. Therefore, an important objective of the network expansion in the next phase of the project is to obtain the sort of diversity that would motivate authentic cross-school collaboration. However, in the current CoVis community the teachers have created the Harm’s Wood activity described above in which all twelve CoVis classes will collect data about the health of a local forest preserve. Because different classes will collect and analyze different data about the preserve, they will have a motivation to work together across schools and across classes in a single school. Ideally, students with shared research interests will be able to combine their individual resources and expertise in pursuing these interests. In an activity such as this, with students either in different schools or in the same classroom at different times working together, the incentive to collaborate will emerge. It is an important goal of the Collaboratory Notebook to support the needs of these collaborative learning activities, and these needs will drive the future development of this tool.

Summary

The design and evaluation of all software is a difficult business. In education, it is particularly challenging because of the number of constituencies involved and the variety of possible evaluation criteria. In this research, we have tried to take into account the complexity of the environment in which learning takes place and the importance of understanding the constraints that face teachers, students, and administrators. The Collaboratory Notebook is designed to support the sorts of collaboration that characterize the practice of science by researchers. It is networked in order to allow students to participate in collaborations that go beyond the boundaries of classrooms and class periods. It is designed to help students structure their own investigations and to make it easy for collaborators to share ideas and experiences with each other. However, the school environment is dramatically different from the scientific workplace and that difference poses important challenges for the Collaboratory Notebook in supporting open-ended science investigations and collaboration.

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