Creating An Inquiry-Learning Environment Using The World Wide Web

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Abstract: The University of Michigan Digital Library (UMDL) Project provides guidelines and design standards for teaching and learning materials and methods to support science inquiry using on-line resources. In this paper, we present an initial report of our experiences using on-line resources to promote sustained inquiry in science classrooms. We examine the challenges faced by teachers and students as well as the challenges posed in creating or finding useful content and in designing the technological tools for students to investigate meaningful questions on-line.

1. Introduction: Motivation & Goals

To promote more in depth student understanding of science, a number of researchers and policy groups (e.g., Brown and Campione, 1995; Linn, 1995; NRC, 1995; AAAS, 1992; CoVis Project, 1996) argue that students need to engage in sustained inquiry activities, formulate authentic, meaningful questions, plan tasks, predict outcomes, argue, evaluate and collaborate. To support students in these new types of activities, it is incumbent upon us to provide them with a new generation of tools; just as professionals engaged in sustained inquiry make continual and routine use of tools, students also need a full compliment of tools designed to meet the unique needs of learners (Soloway, et al., 1994).

In this paper we describe our recent work exploring how on-line resources can be effectively utilized to support sustained student inquiry. While still in its early stages, we have identified a number of challenges to using such on-line resources as World Wide Web sites, and suggest strategies for dealing — to some extent — with those challenges. In what follows we outline the pedagogical philosophy which drives our use of technology; present an overview of our work in schools; and discuss the challenges we have encountered illustrating these with vignettes.

2. Pedagogy First: What is Sustained Inquiry?

Our design of a sustained inquiry project is based on five characteristics (Blumenfeld, et al., 1991; Krajcik, et al., 1994):

- **The Driving Question**. Students investigate authentic, meaningful questions or problems that orchestrate activities and organize concepts and principles. Sample driving questions are: What is the quality of water in the stream behind my school? Where does my school waste energy? Should I wear sunscreen? These sorts of questions are open-ended and authentic — they relate to the interests, needs, goals, and curiosity of students. Key is that the content is explored in the context of pursuing an authentic question.
- **Investigations**. Students investigate the driving question by asking and refining questions, making plans, designing experiments, debating ideas, collecting and analyzing information and data, drawing conclusions, and communicating their ideas and findings to others.
- **Artifacts**. As a result of performing authentic inquiries, students develop a series of artifacts or products that represent their knowledge in a variety of ways.
- **Learning Communities**. Students, teachers, and individuals outside the classroom collaborate to investigate a driving question. Students discuss and try out their ideas and challenge the ideas of others.

- **Use of Technology.** Computers are used as cognitive tools to help learners represent and share ideas and to support students' research. Communications tools enable learners to access information and interact with others.

By engaging in projects, students (1) acquire an understanding of key scientific principles, concepts, and processes, (2) develop important habits of mind, and (3) learn to communicate their knowledge to others (Brown & Campione, 1995; Blumenfeld, et al., 1991).

3. Technology Second: Why the Web

Central to sustained inquiry is access to resources such as information, experimental apparatus, and human experts. Moreover, central to participating in a community is the sharing of findings with the community. On-line technologies afford students opportunities to move beyond their information-poor classroom to access a variety of information resources, as well as providing a forum for publishing their findings. The following characterizes the unique features of on-line resources:

- **Content is current.** Using resources on the Internet, students will obtain the most current information regarding the questions they are exploring.
- **Content can be from primary resources.** In many circumstances, students will use the same data and information sources as scientists.
- **Content is comprehensive.** In typical libraries used by secondary school students, a small subset of popular and scholarly material on a given subject is available. The UMDL and WWW will expand the content enormously, giving students access to an unprecedented range of information sources.
- **Resources are represented in various formats.** In particular, information is available in digital form for easy manipulation and use by students. Video and sound provide new information (for example, dynamic views of the ozone holes), and new ways of receiving information, revealing new possibilities for students to build understanding.
- **Student can publish on-line.** Student artifacts can be shared by a wide audience.
- **Content is readily accessible.** Information is quickly and easily accessible -- literally just a mouseclick away.
- **Students may engage in dialog with scientists to seek information and perhaps to solve problems.**

Inasmuch as on-line resources differ from traditional print and non-print resources, new sets of issues for teaching and learning must be confronted. In what follows, we describe our efforts to employ these features of on-line resources to support sustained student inquiry.

4. The UMDL Project: Status Report

A group of over thirty researchers at the University of Michigan from Information and Library Studies, Education, and Engineering are involved in an NSF/NASA/ARPA-sponsored four year effort to construct the University of Michigan Digital Library (UMDL). Currently, searching the WWW is like going into a library where all the shelves are marked miscellaneous. The UMDL will be a combination digital card catalog and personal library for earth and space science resources; students and researchers will visit the UMDL with their questions and be directed to relevant network resources.

In preparation for launching the UMDL in the spring of 1996, we have been working with three high schools in Ann Arbor (Community, Pioneer and Huron) since January of 1995, to explore how on-line resources can be used to support sustained inquiry. We have developed several curriculum units that are being used in these schools including a tutorial on how to search on the WWW using volcanoes as the subject content, and units on the content areas of ozone and conservation.

During the 1994-95 school year, we worked with science teachers at Community and Pioneer to introduce students to on-line search. During this academic year, we are working with all three schools.

- **Community High School.** We are working with four teachers in four 9th grade science classrooms and four 10th grade science classrooms to support students doing on-line investigations. We are also working with two teachers and four freshman classes to create and publish Web pages reflecting the results of on-line investigations.

- **Pioneer High School**. We are working with two teachers and nine 9th grade science classrooms to support students doing on-line investigations.
- **Huron High School**. During the winter term, we will also be working at Huron with six teachers and 160 freshman students in two interdisciplinary blocks.

Each school provides unique challenges. Community is a small, alternative school, which has one laptop for every two science students. Pioneer and Huron are large, traditional, high schools with limited computer resources. In our work we have taken field notes, collected student journals and Web-documents, and video taped classroom activities. We have used these observations and student artifacts to inform us at various stages in our development.

5. Experiences Using On-line Resources to Support Sustained Inquiry

Technology alone will not by itself serve to support sustained inquiry in a classroom. Rather, all the elements of a classroom — the content/curriculum, the teacher, the student, the technology — need to be restructured in order to take advantage of technology's affordances. The teacher's role, for example, needs to change from the "sage on the stage" to the "guide on the side." Students must take greater responsibility for and ownership of learning activities. The curriculum needs to emphasize inquiry not memorization.

In what follows we describe challenges and how those challenges were met as we introduced on-line resources into the Ann Arbor high schools. The vignettes which we present are representative of our experiences in reshaping the four elements of a high school classroom: the content/curriculum, the technology, the student, the teacher. The vignettes have been selected on the basis of their universality: we feel the challenges we faced are typical and hope our strategies for dealing with them can provide useful insights as others travel the same road.

5.1 Curriculum/Content Challenges

5.1.1 Challenge: How To Scaffold Students Developing Authentic Driving Questions

Developing driving questions is difficult: teachers are typically focused on curriculum and content issues. Their previous experience leads them to ask highly directive questions. For example the driving question asked by one teacher was "Find two examples of contaminants in the Great Lakes." Students are also unused to asking open-ended questions, instead asking such questions as "When was the last volcanic eruption?" and "How many active volcanoes are there?"

Thus, we found that we needed to provide teachers and students with assistance at least in the initial stages of formulating authentic driving questions - questions that are interesting to students, engage worthwhile science content (matching with classroom objectives), and are broad enough to allow students to formulate driving sub-questions. The following are strategies we used to facilitate teachers and students developing good driving questions:

- **Modeling:** One of our research team, who was more versed in facilitating open discussions, actually led the several classes until the regular classroom teachers felt comfortable taking over.
- **Class Brainstorming:** Teachers worked with students to construct lists of usable search terms. Until something is known about the content area, it is difficult to formulate a good driving question, or even search in a meaningful way. Brainstorming drew on students' prior knowledge, which in turn, set the stage for finding information on the Web.
- **On-line Tutorial:** We constructed a set of Web pages that provided examples and prompts to help students develop driving questions and use an inquiry process. For example (see Figure 1), the page gives suggestions to help students think of a driving questions, such as asking themselves "What happens if...".
- **Off-line Materials**: Attempting to compensate for the lack of context support in the technology (see Section 5.2.1), we handed out written materials which provided static reference to the on-line tutorial and clearly explained what the students were expected to do during the class period. For example, the second day's instructions included: "At the end of the period, be ready to describe to the class one site that gave some information that helped you with your question."

While the on-line tutorials were the least used of the supports, most students did develop good driving questions. Though we created materials on the computer, they were not particularly interactive, and were perceived as just another set of written instructions — to be ignored. Modeling open discussions for the teachers was not effective in changing their behavior: the teachers who started with closed questioning did not change their approach — yes/no questions were still the norm at the end of the project.

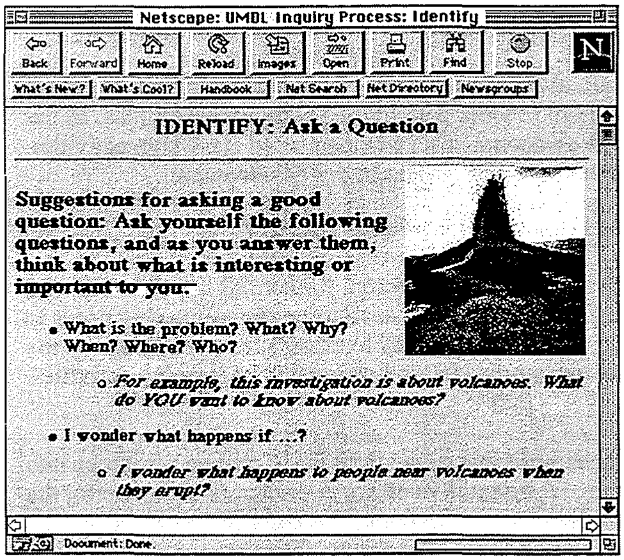

Figure 1: Web page to help students formulate a driving question.

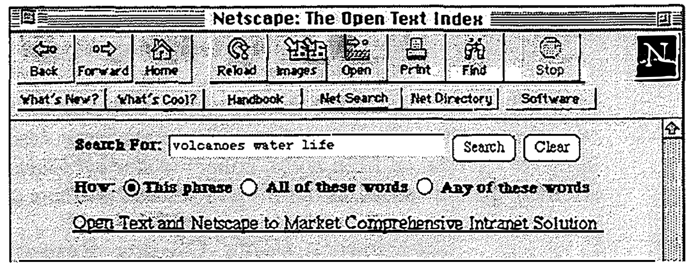

Figure 2: OpenText search form.

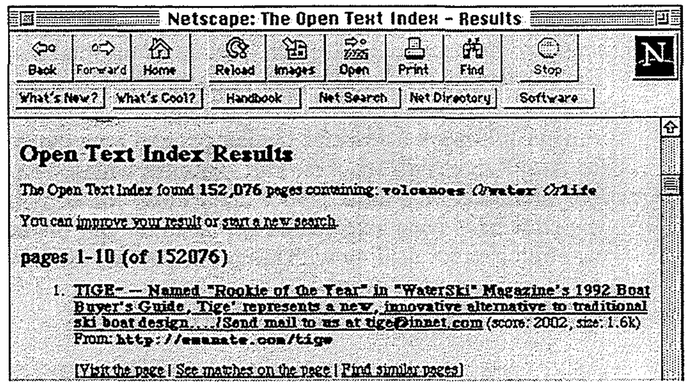

Figure 3: Results from OpenText Search

5.1.2 Challenge: How To Take Advantage Of The Unique Features Of The Web In The Classroom

While textbooks provide text and static images, students can access video, animation, audio, and other dynamic media on the Web — if teachers permit it. In our on-line materials, we suggested students visit specific sites where we knew there were videos (e.g., researchers going into active volcanoes). However, we found on the day of the class that the computer coordinator had removed the QuickTime Movie Player from all the student PowerBooks because the teachers did not want the students to "waste their time watching videos in class." We are working with the teachers to change their minds on what are appropriate information resources in the classroom.

5.1.3 Challenge: What can students contribute to a digital library

Unlike a conventional library, students can publish their work in a digital library. In fact, knowing that they will share their findings with others is an important aspect of motivating students to sincerely engage in an inquiry of their driving question. Additionally, sharing and interacting with others is an integral part of developing a sense of community, which is yet another key pedagogical characteristic of authentic inquiry.

Last fall we conducted a pilot Web publishing project with approximately one hundred 9th grade students at Community High School. Students worked in groups to create Web pages about water contaminants. Each group researched a specific contaminant (e.g. benzene, chlorine, PCBs, DMSO). Students conducted most of their research on-line; the vast majority of information they presented was already on the Web; however, the students transformed and represented this information in a style and format tailored to the needs of high school students, thus adding value to the Web's existing collections.

While publishing on the Web definitely engaged students, we found that many of the student Web pages emphasized form over content. Even when motivation is high and students are engaged for significant periods of time, it is still a challenge to have students seriously grapple with deep content issues.

5.2 Technology Challenges

5.2.1 Challenge: How to Provide Point of View, Context, and History/State

Navigating with the current crop of browsers, such as Netscape, pose real challenges for learners.

- **No point of view**: Unlike a textbook, with which students are familiar, the Internet does not provide a point of view. For example, students searching for information on lava without specifying volcanoes as a domain, also found information on lava lamps. On the other hand, students made connections that textbooks would not have provided, e.g., profession of volcanology, effects of volcanic eruptions on the local weather of Michigan.
- **Few context representation mechanisms:** The Dewey-decimal organized bookshelf provides a great deal of information, e.g., it visually situates one book in a broader context. In contrast, when one website takes up the students' entire computer screen, it is not surprising that students have a hard time perceiving that this website actually is just one piece of a larger context — that may well contain information that should be explored.
- **Stateless/No History:** Current browsers provide bookmarks and history files as the only record of student navigation. These are inadequate because they provide no context and are difficult to maintain from day-to-day.

As we mentioned, students kept journals on paper to compensate for the latter two problems, and class discussions to deal with the first problem. The UMDL is being designed to expressly deal with all three problems.

5.2.2 Challenge: How To Support The Query, Re-Search Process

Teaching search strategies to students is a difficult process. The following example illustrates the inadequacy of expecting a student to understand the process of searching on the Web. OpenText (http://opentext.uunet.ca:8080/) is arguably one of the better Web search engines but it is not designed with a 9th grader in mind. A student wanted to know about the impact of volcanoes on waterlife. The student typed into the OpenText form: "volcanoes, water life"(see Figure 2) - and clicked on search, accepting the default "This phrase." OpenText retrieved zero hits. The student clicked on “All of these words” and again, got back zero hits. He clicked on the third alternative “Any of these words” and got back 152,076 hits! (see Figure 3) Besides being demoralizing, this sequence actually took about ten minutes — of a 50 minute period — as the student discussed with the instructor what was happening.

The issue is not how the screen looks, but in the functionality and scaffolding (Wood, Bruner, & Ross, 1975) that is provided — and not provided — by the interface. While students certainly understand what it means to ask a question, it is not clear that they understand how to engage with a computer-based search engine in query, search, and *re*-search. Currently, the teacher and fellow students provide assistance in this type of situation. However, the technology, again, must bear more of the burden in the future. (e.g., Borgman et al. 1991, Soloway, et al. 1994).

5.3 Student Challenge: How To Support Inquiry And Understanding

As we argued in the Introduction, having students engage in sustained inquiry is difficult. In particular, they must become mindful of what they are doing and monitor their progress closely, as well as understand the content being explored. In a three-day unit at Pioneer High in the spring of 1995, we did not provide support for students in these areas: in their evaluations, students reported that they got lost, and time on the Web was not as productive as it might have been; as they browsed, they didn't keep track of where they had been and what they found, so that in subsequent days of the unit, they had to start over. In sum, there was significant chaos, confusion, and little learning taking place.

To support students in these cognitive and metacognitive activities, we tried two strategies with nine classes in a three-day unit in the fall of 1995 at Pioneer.

- **Journals:** We have students keep written research notebooks in which they record their search steps including: driving questions and keywords, URLs of sites found, and comments about their strategies and experiences. Journals helped students keep their focus and organize their work over the course of the three-day search tutorial. Students could refer back to their search keywords and the URLs and notes about helpful sites. For example, Figure 4 depicts a page from a student's journal; here we see that the student kept track of keywords, trying to narrow her search. She recorded the number of "hits" and moved on to visiting sites and evaluating content after composing a search which yielded a reasonable number of hits. (Rather than having students flip between a word processor and Web pages, on their 12 inch monitors, we decided to use paper notebooks.)

- **On-line Tutorial:** We provided Web pages which structured the Inquiry Process (see Figure 5) by providing starting points and examples.

While the journals were definitely a success, and helped keep the students focused, the on-line materials, though they were crafted and recrafted, were not as effective as we intended. Once students left the on-line tutorial and began to actually search on the Web, they rarely returned to these pages. need to be part of what they're doing, not just an aside! Easily accessible!

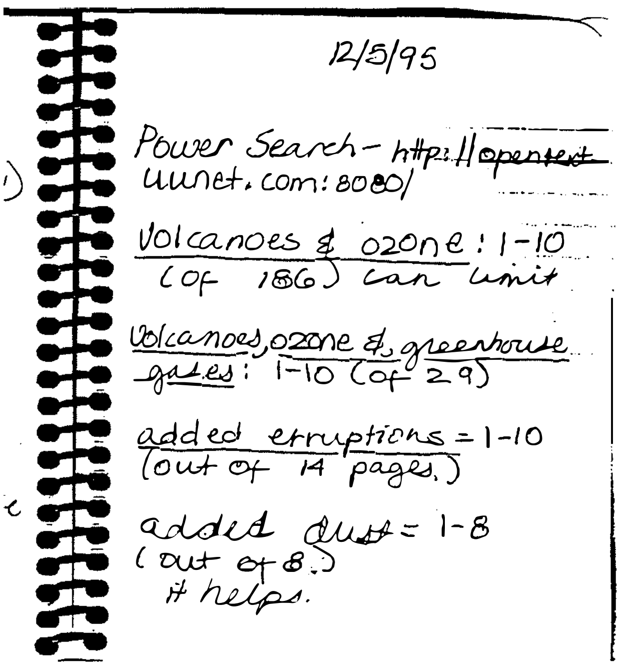

Figure 4: Page from a student journal showing use of the journal to keep track of a search.

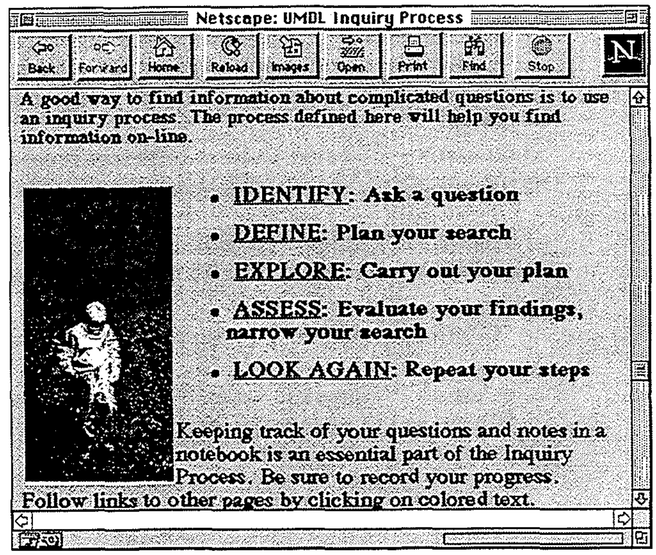

Figure 5: Search tutorial page.

5.4 Teacher Challenges

The most important component of creating a culture of inquiry in the context of the World Wide Web is the teacher, their attitude about technology, their beliefs about learning, and their instructional practices. Thus, it is not surprising that issues of teaching and teachers has cropped up in all sections of this paper. Here we focus on the bigger picture: the role of teacher in creating a climate and culture of inquiry.

5.4.1. Challenge: How to help teachers create a climate of inquiry in the classroom

In an inquiry-based pedagogy, the teacher becomes less a deliverer of information and more a manager and facilitator of the inquiry process — one who is supportive of and provides scaffolds for student-driven exploration (Brown & Campione 1995, Krajcik et al. 1994, Scardamalia &Bereiter 1991). For example, in the prevalent stand-up-and-talk style of teaching, a teacher doesn't want their class to waste time hunting around (i.e. searching on the Web); thus, we saw teachers highly structuring the inquiry, telling the students what to do and what sites to visit. In fact, there is a flavor of this over structuring tendency in our on-line materials, as well; we provided a step-by-step checklist on how to do a search (see Figure 5). While some structuring, some instruction is needed — after all, the students *are* content and process novices — providing just the right amounts is a tricky business.

For teachers, transitioning to this new role of manager and facilitator is exceedingly difficult. In our work with classroom teachers, we have found no single strategy that works miracles. Using a model of teacher change (the CEER Model - Collaboration, Enactment, Extended Time, Reflection and Planning,) we have been able to help teachers develop and adopt and adapt more inquiry-based practices (Krajcik, et al., 1994).

5.4.2. *Challenge: How to encourage the teacher to help students engage in substantive conversations*

We found the most success in encouraging student-driven inquiry when the teacher managed and encouraged classroom conversation among students and between students and teachers. As others (Brown & Campione, 1995, Scardamalia & Bereiter, 1991) have also observed, it is a challenge for teachers to engage in this type of activity. For example, since on-line access is such a precious commodity — at Pioneer High, there is one computer lab with Internet connectivity in the whole building of 2,000 students — teachers did not want to interrupt students. We found that we had to explicitly build in class time for the following types of conversation:

- **Divergent talk**. At the start of the search tutorial, conversation was important to help students recall prior knowledge and begin to focus on the task at hand. The Driving Question posed to them was: "What do you want to know about volcanoes?" They need to have some knowledge of volcanoes to be able to respond with their own Driving Question. Talk — with the teacher helping by asking questions and responding with open-ended answers and additional questions — got students thinking about volcanoes and helped them realize how much they already knew.
- **Exploratory talk**. While working on-line, students talked to their partner and sometimes the teacher about what they were doing and why. Students who were unable or unwilling to talk about content were further isolated, either working alone or watching their partner work. Productive learning occurred when students talked to themselves via their journals, to each other, and to the teacher.
- **Convergent talk**. At the end of the class, we found it helpful to have a class discussion about what students did and why, and what they found. This conversation provides an opportunity for students to evaluate what they have found and to synthesize their ideas. It provides an opportunity for the teacher to model (and thus scaffold) the inquiry process.

A representative example of how difficult it is to support open conversation occurred at one of the schools:

> Several students asked the Driving Question "What is the temperature of lava?" and found differing temperatures, three different "answers" in all. A class conversation ensued about why different numerical values for the temperature of lava were discovered. In this instance, the teacher sought a single answer, asking questions such as "Which one of these do you think is right?" rather than the open-ended questions that could have been asked. As a manager of inquiry, the teacher's stance would have been that perhaps there is no one temperature and the questions that might have been posed to the class could include: Who reported the information? Under what circumstances was the information collected? Is there a scientific reason for differing temperatures of lava?

This episode illustrates a primary function of the teacher as a manager of inquiry: to help students break out of the "one question, one answer" mold and become comfortable with open-ended query.

6. Concluding Remarks

While we agree with the nationwide call to connect kids to the Internet, it is clear that without a great deal of effort on the part of teachers, curriculum designers, administrators, parents, *and students*, no great advancements in learning will take place. While only a thimble-full, the vignettes and guidelines reported here are concrete examples of how much change is needed in order to take advantage of what on-line resources afford.

If the current goals and instructional practices remain in effect, there is no reason to go through the enormous effort of installing Internet connections into the classroom: if the most that students are asked to do is write two page reports on some topic, then the library's trusty encyclopedia and reference books are all sufficient. However, if we sincerely embrace inquiry-based learning, Internet resources will be a key support mechanism. Changing from the dominant educational view — didactic instruction — to a more constructivist, inquiry-based model is truly the quest — and test — of our society's commitment to children, to learning, and to a future where we educate not just the top 20% of children, but *all* children.

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