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ABSTRACT

The recent introduction of the Internet into classrooms provides an opportunity for learners to access a wide range of digital resources on the World Wide Web. The development of on-line learning materials can support inquiry-based activities for students as they pursue questions of interest, plan searches, and analyze their findings. This paper traces the design evolution of these materials as part of the University of Michigan Digital Library project for implementation in middle and high school science classrooms. The reasons for the inclusion and modification of various design features are explained, and questions are raised that remain as the design process continues. As a result of this research, a number of challenges in designing on-line learning materials for accessing digital resources on the World Wide Web are described. Recurring themes in the design evolution include the following: 1) movement from text-heavy pages to short, graphical, more interactive pages; 2) movement away from providing on-line context to providing directional and navigational aids depending on the classroom instruction to the context; and 3) use of consistent design elements may provide a consistent on-line environment for learners which may help reduce cognitive load. Contains 27 references. (Author/PVD)

On-Line Learning Materials For the Science Classroom: Design Methodology and Implementation

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Abstract

The recent introduction of the Internet into classrooms provides an opportunity for learners to access a wide range of digital resources on the World Wide Web. The development of on-line learning materials can support inquiry-based activities for students as they pursue questions of interest, plan searches, and analyze their findings. This paper traces the design evolution of these materials as part of the University of Michigan Digital Library Project for implementation in middle and high school science classrooms. We explain the reasons for the inclusion and modification of various design features and raise questions that remain as we continue the design process. As a result of this research, we describe a number of challenges in designing on-line learning materials for accessing digital resources on the World Wide Web.

On-Line Learning Materials For the Science Classroom: Design Methodology and Implementation

Across the United States, schools, states, and the federal government are making enormous investments in Internet technology. As students log on with increasing frequency, research about educational applications of the Internet is becoming increasingly important to educators. The Internet has great potential as a tool for sharing resources, accessing information, collaborating on activities, and engaging in new educational activities we are only beginning to invent. On-line resources have particular potential for supporting inquiry-based learning, and our research has focused on the use of World Wide Web information resources as part of inquiry-based projects in both middle and high school science classrooms.

By inquiry-based projects, we mean activities which extend over several weeks or more, in which students ask questions, design and implement investigations, participate in learning communities, use scientific tools, and create artifacts (Blumenfeld et al., 1991). Inquiry-based projects can include experimentation as well as information seeking. Successful inquiry projects require a supportive classroom environment which encourages students to ask engaging questions, seek information, and construct their own answers or solutions. The National Research Council (1996) describes inquiry as:

> ... a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (p. 23)

A problem that teachers face in creating an inquiry-based learning environment is making adequate resources available so that students can answer their own questions. A solution to this

problem in the past has been to package a set of materials about a given subject, creating a self-contained and highly controlled body of material. However, a new alternative has become possible with the World Wide Web, and even better resources may become available in the future. With these on-line resources, students can access enormous collections of information about a wide range of subjects, including raw data and other scientific information, current events, and information directly from commercial, governmental, political, and personal sources. The questions we are asking are: How can these sources of information be effectively used by students as part of inquiry? How can students navigate complex information spaces to answer questions which they pose? How can these resources make teaching through inquiry easier for teachers?

This study is specifically about designing on-line learning materials for inquiry-based activities on the World Wide Web. Given the existing Web environment – browsers, search engines and architecture – how can materials be designed to afford effective implementation of inquiry-based learning? Can on-line learning materials help students and teachers take advantage of the unique characteristics of Web-based resources? Are there design principles that can provide a guide to the creation of effective on-line materials?

In this paper, we will present design principles we have developed while creating on-line materials as part of the University of Michigan Digital Library (UMDL) project. After a brief overview of the project, we will describe our fundamental design theories, our development process, and our early design efforts. Then we will discuss the evolution of specific design features in five categories. Finally, we will summarize our conclusions about successful principles and persistent problems.

The UMDL - MYDL Project

The University of Michigan Digital Library (UMDL) is a project that brings digital resources into classes in grades 6 through 12, with funding from the National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), and Advanced Research Projects Agency (ARPA). Within this project, the UMDL Teaching and Learning Group has been developing teaching and learning materials to support science inquiry using on-line resources. The part of the project focusing on the middle-school level (grades 6-8) has been called the Middle Years Digital Library (MYDL) project. In the spring of 1995, we began to install hardware and software necessary to access the Web and eventually the UMDL into middle and high school classrooms. As of winter 1997, we are working in three high schools and four middle schools with over twenty teachers and five hundred students.

On-line activities in the high schools vary considerably. At one high school, students work on research activities related to their science curriculum for a two to three week period, including five or more on-line sessions during which the entire class works in a computer lab. During the year, they complete four such activities. At another high school, students have access to computers from their science classroom; their use of on-line resources is a routine part of classroom activities for all content areas during the year.

At the middle schools, sixth grade students are introduced to on-line resources through a "Scavenger Hunt" which includes four days on-line using a tutorial-like set of Web pages to learn to use the Web browser and search engines, to become familiar with the structure of our site, and to get a feel for the Web in general. The Scavenger Hunt is followed by four content units during the year in the topic areas of weather, astronomy, geology and water ecology. During the on-line activity, students are asked to pose a question of interest to them about the content area – a "driving question." Their question-asking is supported by classroom activities, including brainstorming questions as a whole class or keeping a running list of driving questions as the content unit unfolds. Students work in pairs to browse the Web, searching for relevant

information about their question. They may also spend some time in the library using print resources. At the end of the activity, they present a report or other artifact.

Part of the effort of the UMDL/MYDL has been to create on-line materials for use in scaffolding on-line activities for high school and middle school students. Below we discuss our design methodology.

Design Issues

In constructing Web-based learning materials, we considered a number of issues relating to the nature of on-line information, on-line instructional materials, hypermedia structure, and Web page design. These design issues were intended to provide a framework for developing accessible, engaging, and informative materials for students in middle and high school science classrooms.

Several characteristics of on-line information are significant in designing learning materials. Although they are not individually unique to on-line materials, taken together, they are quite different from the resources normally available in K-12 schools and classrooms. The characteristics which we have focused on in our design of learning materials are:

1. Content is current. Using on-line resources on the World Wide Web, students can obtain up-to-date information in many content areas.
2. Content can be from primary resources. Students can often use the same data and information sources as scientists do.
3. Content is comprehensive. In typical libraries used by secondary school students, only a small subset of popular and scholarly material on a given subject is available. The Web expands the range of content enormously, and in the future digital libraries may do so even more.
4. 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 resonant sounds of earthquakes), and new ways of receiving information.

5. Students can publish on-line. Students can produce content to share with others on-line.
6. Students can collaborate on-line. They may have access to other students doing similar activities or to experts in their field of study.
7. Content is readily accessible. Information is easily obtainable from a single point of access. That is, students can acquire a variety of information through a single computer.

In addition to the unique characteristics of on-line information, Web-based learning materials are different from both traditional printed and other technology-based materials such as CD-ROMs or laser disks. Several of these characteristics have been particularly important for our designs. First, the learning materials are available to a large audience, and unlike packaged computer software, they can be accessed on any hardware platform. Secondly, on-line learning materials can include interactive elements such as sharing and collaboration within the environment itself. Finally, having learning materials on-line allows developers to modify the content easily and provide users with timely, simultaneous updates.

Literature on learning through hypermedia also provides guidance for fundamental decisions in designing Web materials. While hypermedia has potential benefits, navigation in hypermedia systems can also cause confusion and disorientation (Heller, 1990; Jacobson, 1995; Jonassen, 1986; Marchionini, 1995; Nielsen, 1990), because users often have frameworks for organizing information that are different than the system's. To avoid this disorientation, navigation structures in on-line systems must be apparent to the user (Bornman & vol Solms, 1993; Nielsen, 1990). Salampasis (1995) describes hypermedia problems as "interrelated" but "a natural consequence of explorative navigation." As users stop to think about the selection of a path to navigate, they can become disoriented, leading to a increase in cognitive load and frustration. Jonassen (1990), has shown through experimental evaluation that although users

enjoy the exploratory nature of a hypertext environment, the resulting increase in cognitive load may cause them to view books as "easier to read and more accessible than hypermedia systems."

On the Web in particular, users require a high degree of predictability and hierarchical structure, with clear graphical and functional continuity to ease the user's cognitive load in unfamiliar Web sites (Lynch, 1996). To maximize visual sensation and interest, but not overwhelm the user, there must be a balance between textual information, graphical design, and interactive hypermedia links. However, excessive graphics and complex images should be avoided to prevent alienating users who would experience long download times when accessing the site with a modem line (Lynch, 1996).

The use of icons for navigation buttons presents a particular challenge as there are few images that are "unambiguously understood across all computer interfaces and international borders" (Apple, 1992; Horton, 1994; Marcus, 1992; Microsoft, 1992; Norman, 1988, 1993). Text-labeled buttons are considered essential to clearly identify a button's function. To take advantage of the flexible nature of materials on the Web, Lynch suggests that on-line pages be modular in design, and complex pages be reduced to smaller sections for easy updating without reformatting large paragraphs of information.

Development Process

Our materials were developed through many cycles of design, modification, testing, and analysis (see Figure 1). This iterative process has some features in common with the rapid prototyping software development model. (Wilson, Jonassen, & Cole, 1993). Maher and Ingram (1989) assert that rapid prototyping allows users to try out the system, discover problem areas, and provide input into the selection of alternatives to the design. This methodology works well for the design of Web pages, because they are easily modified and rewritten. Specifically, we built several versions of our materials, tried them out in classrooms, obtained feedback, and made modifications based on the feedback.

Development Overview

The design cycle for our materials can be divided into three major phases: (1) early designs, which include unimplemented materials and the first materials used in classrooms; (2) interim designs, which included a wide variety of experimental features and modifications; and (3) current designs, in which many design principles have begun to stabilize (see Figure 2).

The first design was piloted with a group teachers, and feedback from these materials was a starting point for the development of additional learning materials for a variety of sixth and ninth grade physical science content units, including Astronomy, Geology, Water Ecology, and Weather. The learning materials augment major units covered during the school year, providing an avenue for students to ask questions of interest and pursue their own investigations.

Our first feedback on how students interacted with these materials occurred with 200 ninth grade physical science students at a local suburban high school. Since the initial implementation, the project has grown to include over five hundred students in seven schools, in sixth and ninth grade. We employed a variety of data sources during these testing periods, specifically focusing on what students were doing while on-line and how they were using the learning materials. These sources included classroom video, field notes, situated interviews, informal observations and discussions with students, and a form of data we call "process video" in which a student's screen activity and accompanying voice is recorded on videotape. In addition, interviews and group discussions with teachers provided insight into the degree of success that students were experiencing while investigating science topics on-line.

Early Designs

We began our design in the spring of 1995 with a survey of various Web sites that provided educational materials for middle and high school students. At that time, few Web sites offered materials appropriate for use in the classroom. Educational sites focused on providing materials for teachers, or on organizing collaborative activities across a number of geographically separated sites.

Working with teachers at three high schools, we began to design materials for use by content area teachers in whole-class settings. Our initial design was based on several criteria:

- The site should be designed for a high school audience in terms of both reading level and scientific content.
- It should provide enough background information to help students contextualize the information they found.
- It should be self-explanatory, in the sense that teachers or students not in our project could use the sites without our assistance.
- It should foster inquiry-based learning, not giving answers but rather providing scaffolding to help students generate questions and seek information.
- It should be easily navigable using consistent graphical icons, table of contents, and other organizational tools, placed strategically to help users understand the structure of the site.

Our initial design, with materials related to "ozone," was piloted with teachers in the summer of 1995, prior to classroom implementation scheduled for autumn 1995. Feedback from teachers led to several changes before classroom implementation. These included:

- Less background information. Teachers were not inclined to read what we provided on-line; they were interested in getting to the Web, as we later found with students.
- Graphical, representational icons. Our first set of buttons for moving from page to page were numbered boxes – during the pilot activity we changed these to graphical icons shown in Figure 3.

- Fewer links to outside sites on the explanatory pages. We found that users left the UMDL site to visit the links we provided and frequently didn't come back. By reducing the number of links, we hoped to maintain their attention so they could take advantage of our materials.
- Shorter pages. Our first design consisted of very long, text-filled pages with many navigation tools. However, we observed that most users in the teacher group did not reach the bottoms of the pages, and were eager to move on.
- Less specific instructions. Figure 4 shows part of the activity instructions for the original ozone unit. Within the test group, several teachers had creative ideas about how they would use the materials – their ideas were very different from what we had planned. Giving such specific instructions on-line limited the usefulness of the pages for many teachers.

Overall, piloting our initial design led us to realize that the aesthetics and interactivity of the pages were very important. We did not want to provide static materials, but rather we wanted to frame science content with on-line materials that teachers could integrate flexibly into their classrooms and curricula.

Development of Specific Features

Ongoing iterations and subsequent feedback provided many cycles of revision in which we worked to match the tool and task to the user. An analysis of our design efforts enabled us to categorize our development into five major areas: general design issues, navigation, content/context, interactivity, and standardization. General design issues encompass the overall nature of the on-line environment including appearance, appeal to users, and performance. Through the use of various support structures and location cues, navigation features allow users to browse on-line materials, easing cognitive load and disorientation. Content/context includes our efforts to create materials which could be part of an authentic investigation, by framing the problem in an interesting way and providing a variety of scaffolds to assist learners as they use on-line resources. Interactive features allow users to engage in the investigation and utilization of

learning materials by sharing questions, on-line sites, and comments, thereby encouraging collaboration with larger audiences. Finally, standardization refers to the common "look and feel" of the materials that distinguishes them from other sites on the Web. Table 1 presents a view of these categories, accompanied by specific design features and history of their implementation during the entire design cycle.

In order to understand our rationales for the design and subsequent modification of particular features, the sections below first provide descriptions of our early designs, then observations and rationales that lead to subsequent modifications, and finally summaries of outstanding questions for each category.

1. General Design

Graphics

- Early Designs. With the exception of navigational icons, our initial designs contained few content-related graphics. Our main concern was to provide a significant amount of textual background information, and as a result we did not include graphics relevant to content.
- Design Evolution. In pilot activities with teachers and subsequent use with students, we found that users bypassed pages containing too much text or lacking visual appeal. Over several iterations, we developed new pages containing more clip art graphics related to the context of the unit. We expected that the use of graphics would help engage students with the materials and provide a visual context for their investigation. Figure 5 shows the layout and selection of graphics for the home page of a Middle Years Digital Library geology unit for sixth grade. The notion of the use of graphics to motivate students is supported by Mauldin's 1996 study of the middle school student's feedback on design attributes of computer software. She cites that students requested "high-quality, colorful graphics" in the design to maintain their attention while using the software.

Length of Pages

- Early Designs. Our initial attempts at providing on-line materials included long pages that required the user to scroll down to view the entire document. We thought that users would benefit from accessing a large amount of background information on a single page.
- Design Evolution. During initial sessions, we observed that few students scrolled through a page to determine its content. Instead, they would glance at the first few lines of text to judge the appropriateness of information. This initial habit quickly led to a clicking and glancing strategy for many students, causing them to miss a significant portion of information available at our site and many others. Based on these observations, we modified our materials, creating succinct pages with important information clearly in the browser window. This allowed students to obtain relevant information quickly during their investigations. The notion of short pages is supported by Lynch (1996) as he describes that long Web pages require users to remember too much information and cause them to "lose sense of the context."

Loading Speed

- Early Designs. Because of slow connection speeds at the middle and high schools in the project, download time is a real concern in our Web site design. Our initial materials were mostly text with few graphics, which avoided long download times. We reasoned that students would become disinterested, and teachers would object to wasting time, if pages took too long to load.
- Design Evolution. Initial sessions with teachers and students demonstrated that our materials loaded very quickly. However, as other design issues were considered and pages modified to include a variety of graphics, download times increased. Observations confirmed that students became distracted while waiting for pages to load into the browser. Waiting more than several seconds caused many students to become distracted, and as a result they often strayed far from the immediate task and purpose of the investigation. Rarely did students discuss strategies or specific issues while waiting during these long download times. This problem was complicated during afternoon sessions as Internet traffic increased causing

further delays in loading graphic and text intensive pages. Although the addition of attractive graphics on various sites improved student engagement, long download times seemed to negate those positive effects. As a result of this series of observations, we incorporated new designs that split larger pages into smaller pieces which loaded more efficiently.

Representation of Information

- Early Designs. Initial designs utilized a textual approach for representing information. Graphical icons provided navigational cues within the site.
- Design Evolution. Testing sessions with students indicated that the majority of students did not pause to read textual directions present at our site. We worked toward an interface requiring a minimum amount of reading, relying on graphical images to represent page content and desired actions. Our current iteration incorporates the use of short phrases, graphical icons, and lists of information rather than long paragraphs of text. This graphical interface (Figure 6) allows students to obtain information quickly and easily, and as a result improves their interaction with our materials.

Outstanding Questions

While we have tried a number of designs in which we moved from text to more graphical features, and from longer to shorter pages, we have yet to resolve the issues of how to create a good balance between graphics and loading speed, between the length of pages and the number of different pages needed, and between text and graphics.

2. Navigation

Navigation Bar

- Early Designs. Our first designs incorporated a series of clickable icons with labels accompanied by hypertext (Figure 3). The navigation bar was placed near the top of the majority of pages, and we anticipated that students would easily interpret icon images and

navigate without confusion. Other early designs experimented exclusively with hypertext without icons for navigation, placing them at the bottom of many pages within the site.

- Design Evolution. Field observations revealed that users were often confused as they navigated within our site. The inconsistent placement of navigational tools on some pages caused students to become disoriented. In addition, the images used for icons did not seem to afford users any advantage in the navigation process. An episode captured on process video showed a particular student that clicked the "Back" button on the browser many times to return to a particular page in our site when the use of the navigation system would have returned him to the same location with a single click. As a result of this feedback, current designs include a common navigation bar at the bottom of every page within all MYDL sites. Icons were eliminated and replaced with six textual buttons (Figure 6) to conserve screen space and avoid scrolling pages.

Site Location Cues

- Early Designs. This feature was not included in early versions of our materials.
- Design Evolution. Students continued to become disoriented in terms of their whereabouts in our site, despite the implementation of common navigational tools on each page. Current designs incorporate a "U R Here" graphic, represented in Figure 6, which points users to their current position within the site. It was anticipated that this navigational pointer would improve a student's sense of orientation as they interacted with our on-line materials.

Site Map

- Early Designs. This feature was included in early versions of our materials only implicitly, as a hyperlinked Table of Contents on the starting page of the materials.
- Design Evolution. Testing sessions indicated that the majority of students used only a few pages of the site we provided. Review of process video indicated that students often took the shortest route to on-line search engines, bypassing our links to age and content appropriate

sites and other materials we provided. In addition, some students became frustrated and disoriented due to the complexity of our site. The current design (Figure 7) incorporates a clickable "Road Map" that permits students to view the hierarchical structure of the site while orienting them to the pages available. In addition, the map allows students to visualize the site and navigate to a page by clicking that page's icon. The advantages of a hierarchical site map, are supported in a variety of hypermedia research. Staninger (1994), describes how making students aware of the relationship between groups of facts "helps them to develop associations with which they can assemble knowledge." Conklin (1987), writes that a "graphical map-like browser" can help users explore the realm of a system and avoid the problem of disorientation. In addition, Nelson (1994) supports the notion of using a semantic map, suggesting that authors of hypermedia documents should incorporate systems that "explicitly communicate the relationship between the nodes of information." To promote the use of the Road Map throughout the site, the current design includes two methods for navigation to this page from other locations in our site. Figures 5 and 6 shows a "See the Road Map" icon at the bottom of the page, while Figures 8 and 9 display a small truck icon next to the page header, which allows users to click and transport themselves to the Road Map.

Outstanding Questions

We have tried to provide appealing and efficient tools for navigation, but students still tend to use more obvious though less efficient such as the "Back" button. We need to find ways to make our navigation tools easier to use and more apparent to the students.

3. Content/Context

Contextual Background

- Early Designs. Our first attempts at providing on-line learning materials included extensive background information written with hypertext links to related Web sites and some graphics for illustration. Our idea was to provide students with a starting point from which they could acquire basic knowledge to generate questions and conduct searches.

- Design Evolution. In pilot activities with teachers, and in the first activities with students, we observed that users left our site through interesting links and often did not return to make use of our materials. Those who went through our materials systematically often did not read the text we provided. Over the course of our designs and observations, we have streamlined the on-line materials, eliminating background information and hypertext links to external sites. Although they include content-related graphics, the materials have become a framework for inquiry activities, and make no attempt to contextualize the subject through content.

Links to Content Sites

- Early Designs. With both in-line hypertext links to relevant sites (including a glossary of terms) and a list of "Places to Start," our early designs attempted to create interactive documents for use by students.
- Design Evolution. The lists of starting points proved valuable because they gave students a clear path to useful sites once they formulated a question, but the links were unorganized and the content of the sites was not always at an appropriate level. In response to these preliminary findings, we have put an emphasis on finding useful, age appropriate sites for these links, and on organizing them in ways that make them easy to understand. All links are now provided in tables on "Places to Start" pages (Figures 8 and 9), where they organized by subject headings, and there is a short description for each link. In-line hypertext links to content sites and glossary terms have been removed.

On-Line Help

- Early Designs. Help was an integral part of the early designs. Through text and page structure, on-line materials went through the inquiry process explicitly, giving instructions and explanations.
- Design Evolution. Students did not read the instructions and explanations that we provided on-line. Using feedback from the classroom during one activity, we reduced the amount of instruction to what seemed to be minimal and returned to the classroom the next day only to

observe that even a minimal amount was too much. It seemed that students were too eager to do something on-line to stop and read directions. Because it seemed important to provide a clear explanation of what we meant by "the inquiry process" and what we expected students to do, we developed a separate help section - our "Investigation Wheel" (Figure 10) - which was linked to the materials on every page. This clickable image allowed students to view hints relating to exploring their topic, formulating driving questions, planning and performing searches, assessing results, recording information in their journals, and creating artifacts. Again, we observed over a number of classroom activities that students did not use these pages. In response to these observations, support for the inquiry process is no longer provided in our current materials. The consistent structure of the materials provides some scaffolding for students, but explicit help and instruction is now incorporated into classroom activities by teachers in the project.

Subject Tree

- Early Designs. This feature was not included in early versions of our materials.
- Design Evolution. We observed that students needed more scaffolding to help them recall prior knowledge and generate keywords. Providing textual information proved unsuccessful in early designs, so we looked for other ways to give students additional information and structure for their investigations. A graphical overview of the subject, in the form of a hierarchical structure, could provide such scaffolding. Because of limitations of Web browsers, we have been unable to create satisfactory interactive subject trees. Figure 11 shows one of our subject tree designs. However, preliminary tests indicated that the leaves led to confusion about what was clickable, so this design has not been used in the classroom.

Keyword Help

- Early Designs. Early pages gave keyword hints by providing sample questions and extracting keywords from them. These hints were an integral part of on-line materials. We also

provided appropriate terms linked to an on-line glossary that students encountered on various pages.

- Design Evolution. Test users rarely used the glossary, and those who did end up on a glossary page often found it disorienting. This feature was eliminated before classroom use. Students regularly used our questions and keywords verbatim rather than using them as prototypes to help create their own questions. Still, students needed more help with generating keywords as well as with spelling. One episode captured on process video revealed a pair of students entering a misspelled keyword for eruption (they spelled it "erruption"), resulting in the return of zero search results. They continued to re-enter their keyword, apparently reasoning that it was spelled correctly, and were frustrated by the lack of progress. However, at one point they accidentally entered the correct spelling and were further confused why it would work one time and not the next. Current pages offer the option of getting keyword help on a frames page (Figure 12). Keywords are not immediately presented to students to avoid having them simply copy the words provided, but they can request a list of possible words to use. The subject tree and reference links, described elsewhere, also provide scaffolding for keyword generation and spelling.

Reference Links

- Early Designs. Our first pages included an on-line glossary, and attempted to provide resources in a mini-reference format that could be accessed by students as they read our background materials.
- Design Evolution. As described above, students did not read the text we provided, and test users found the glossary confusing. As a result, current designs include a page that can link students to a set of standard reference materials on-line. Figure 13 shows a clickable image map that allow students access to an on-line version of Roget's American English Thesaurus, the McGraw-Hill Encyclopedia of Science and Technology, and the American Heritage Dictionary.

Outstanding Questions

While we started with materials which were rich in background material and links to related resources, we quickly moved to providing sites that were primarily navigation aids and directions. There are still many ways of providing on-line content and context that we have not attempted in our designs. In particular, we are exploring various ways to support students in keyword searching, such as subject trees.

4. Interactivity

Active Pages

- Early Designs. Initial designs included a majority of text filled pages with hypertext links to other locations within the site. Students interacted with materials primarily through reading and navigating to other pages.
- Design Evolution. Testing with teachers and students indicated that users did not interact with much of the materials we provided. Instead, they would often bypass large sections of text and leave our site for materials found elsewhere. In response to these observations, the current design eliminated the majority of passive materials, replacing them with pages that required students to take some form of action beyond reading. For example, previous iterations included text that encouraged students to record interesting sites in a written journal and share them with another students in the classroom. This was replaced by an on-line sharing form, which automatically posted reviews of sites to a web page where students could view each others critiques and ideas.

On-Line Sharing

- Early Designs. This feature was not included in early versions of our materials.
- Design Evolution. We reasoned that students might benefit from sharing their ideas and information with others on-line. Current designs (Figure 14) include on-line sharing forms where students can post driving questions, share their review of on-line sites, and make

comments or ask questions. Although the current system provides only asynchronous sharing (students do not communicate in real-time), it allows students to view others' work, provide feedback, and become comfortable with sharing their own ideas. Krajcik et al. (1994) describes the benefits of creating a forum where students can try out ideas and challenge the ideas of others. This "sharing" can lead to a sense of community where "knowledgeable individuals share information, data, resources and ideas." Student motivation could increase as a product of sharing questions, comments, and reviews with a wider audience and viewing their work in a public forum such as the Web.

Outstanding Questions

Increased interactivity is a new feature of Web materials. We have yet to explore the possibilities of this on student motivation and learning.

5. Standardization

Common Design Template

- Early Designs. As we experimented with various features and layouts, initial designs did not adhere to a single design template.
- Design Evolution. As part of our commitment to produce four new middle school content units, we incorporated a common template for those designs in early 1996. The current design uses a common graphics, navigation bars, icons, and overall structure. As students become comfortable with the structure and operation of pages, we anticipate that they will be more likely to take advantage of the materials and supports we provide. Lynch (1996) supports the idea of a common "look and feel" between units, explaining that carefully organized graphics and user interface elements can "clarify and reinforce Web site structure, and ease the user's cognitive load" as they encounter similar pages.

Text and Background Color Cues

- Early Designs. Initial designs used black text and a gray background for all sites.

- Design Evolution. Initial observations indicated that students were often unsure of their location on the Web. Other sites contained black text and gray backgrounds, as did ours, and students didn't know if they were in or outside of our site. In addition, changing background colors, images, text, and layout of other sites added to their sense of confusion as they moved from page to page. To reduce the disorientation that students experienced, a light blue background color was applied to all pages to alert students that they were inside the MYDL site. We reasoned that this common color cue could alleviate the disorientation that students experienced as they clicked through a variety of sites and pages. In addition to the background color, a red text color was reserved to indicate that some type of action was required by the student. For example, Figure 5 contains the phrase "Ready? Click on the blue words or use the buttons below" written in red to promote action by the student.

Outstanding Questions

We now have standard design templates for middle school and high school materials. We would like to create templates which could be used by non-experts to create their own materials. It would be of value to study the usefulness of such templates.

Summary

Our use of iterative design techniques continues as we evaluate and modify our on-line learning materials based on feedback from students and teachers. The recurring themes in our design evolution are reviewed below.

1. We have moved from text heavy pages to short, graphical, more interactive pages.
2. We have moved away from providing on-line context to providing directional and navigational aids, while depending on classroom instruction to set the context.
3. Our early designs attempted to provide on-line support for investigations. These supports were removed in later designs, with support being provided through classroom instruction.
4. The use of consistent graphics, colors, and visual cues may provide a consistent on-line environment for learners, eventually helping to reduce their cognitive load. In addition it

provides a template for design which has been useful for easy implementation and modification of new materials.

5. We are beginning to experiment with tools to let students contribute to on-line resources. Such interactions may encourage more thoughtful involvement with on-line materials.

Observations of students using our materials are being used in the design of a new tool for accessing the University of Michigan Digital Library, an interface called Artemis. In addition, we continue to collect data and analyze the behavior of students on-line, in an effort to help both the research and education communities find better ways to structure on-line learning materials for the science classroom.

Note: The complete collection of UMDL - MYDL on-line learning materials can be found on the World Wide Web at: http://mydl.soe.umich.edu/

Table 1
Introduction and Modification of Design Features for On-Line Learning Materials

Design Category	Feature	Design Cycle			Rationales
		Early Design (9/95 - 2/96)	Interim Design (3/96 - 5/96)	Current Design (6/96 - 1/97)	
1. General Design	**Graphics**	Minimal graphics, for navigation only.	Use of clip art graphics.	More engaging, cartoon-like graphics.	Engaging graphics more motivating.
	Length of pages	Long pages with a large amount of information on each.	Shorter pages; less scrolling necessary.	Further reduced pages to little or no scrolling.	Students did not read long, scrolling pages.
	Loading speed	Fast (little or no graphics).	Large graphics slowed the loading of pages.	Reduced size of graphics to increase loading speed.	Students become distracted while waiting for pages to load.
	Representation of information	Largely textual directions and cues.	Textual directions and graphical cues.	All information conveyed with graphics and short phrases.	Students did not read long sections of text.
2. Navigation	**Navigation bar**	Large navigation buttons and text	Small navigation buttons with text.	Small navigation buttons with text.	Large icons wasted space, images did not encourage use.
	Site location cues	Not considered.	Not considered.	Pointer on navigation bar indicates present location within site.	Helps students stay oriented within the site.
	Site map	Table of contents.	Textual site map	Graphical site map.	Facilitates navigation by providing an overview of the site.
3. Content/Context	**Contextual background**	Extensive textual background information.	Removed.	Removed.	Attempted to provide background information on-line, but students did not read it; context now provided by teacher.
	Links to content sites	Single long list of links; links embedded into text	More attention to grade appropriateness and reading level. Sites arranged by category.	Links graphically organized by categories.	Provides students with structured information useful in starting their investigations.
	On-line help	Integrated into unit.	Separate help section.	Removed.	Attempted to provide support for investigations, but not used; support now provided by teacher.

	Subject tree	Not considered.	Hierarchical graphical representation of subject content.	Planned for next revision.	Attempted to provide a context and overview of subject terms to help in searching.
	Keyword help	On "search" pages.	In separate help.	In some units, included as a "frame" next to search engine page.	Students have trouble choosing appropriate keywords on their own.
	Reference links	Not available.	Not available.	Provides links to on-line reference materials.	Students can look up terms and check spelling without leaving the computer.
4. Interactivity	**Active pages**	Most pages static, textbook-like.	Most pages still static.	Each page requires action beyond reading.	Interaction encourages involvement and commitment to inquiry.
	On-line sharing	Not considered.	Not considered.	Students can post and view driving questions and site reviews.	Sharing encourages involvement and thoughtful writing.
5. Standardization	**Design template**	Experimentation with various designs.	Working toward a standard design.	Standard design template for units at each grade level.	Allows easier creation of new units with standard design features.
	Text & background color cues	Not considered.	Unified background color across units, meaningful color scheme for text.	Made color scheme more distinct.	Reduces students' disorientation on-line.

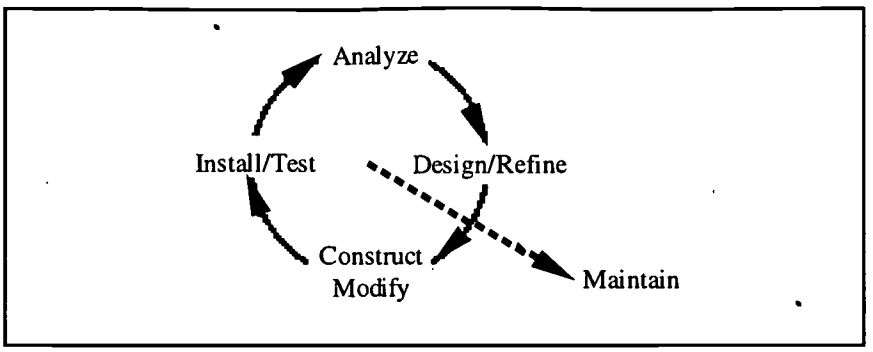

Figure 1. Iterative design process

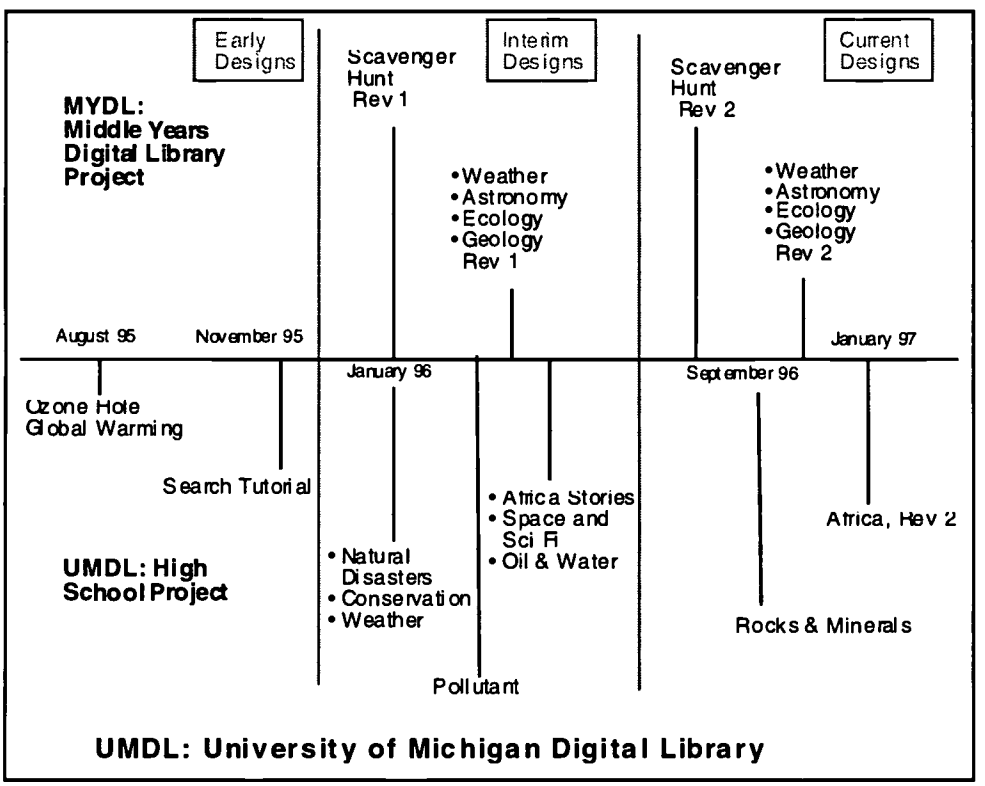

Figure 2 UMDL - MYDL project development timeline

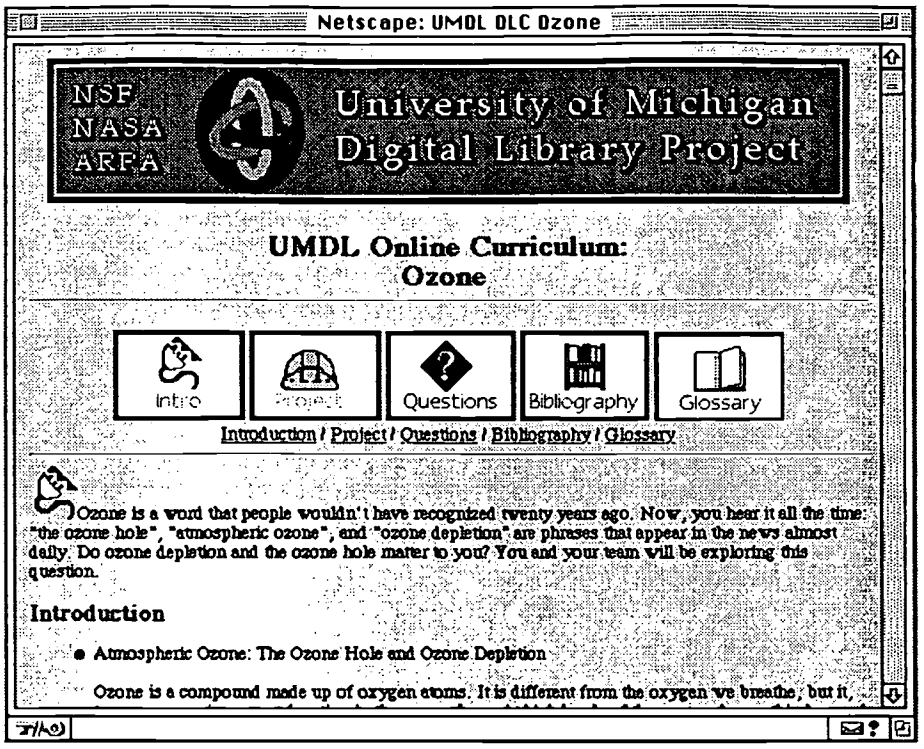

Figure 3. Ozone Unit Home Page

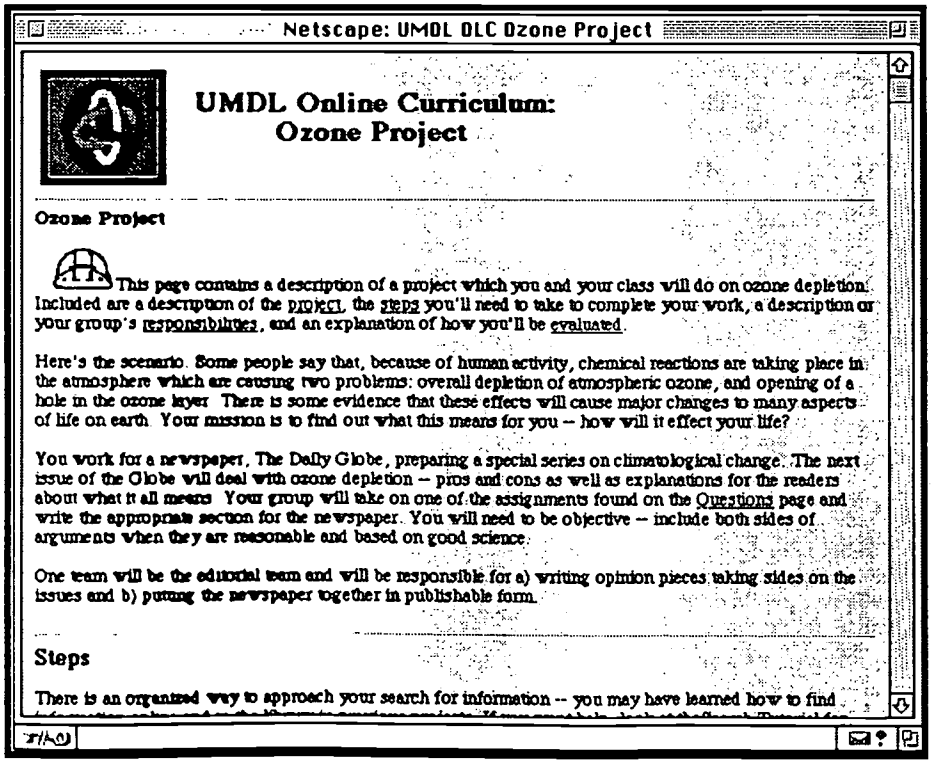

Figure 4. Ozone Project Instructions

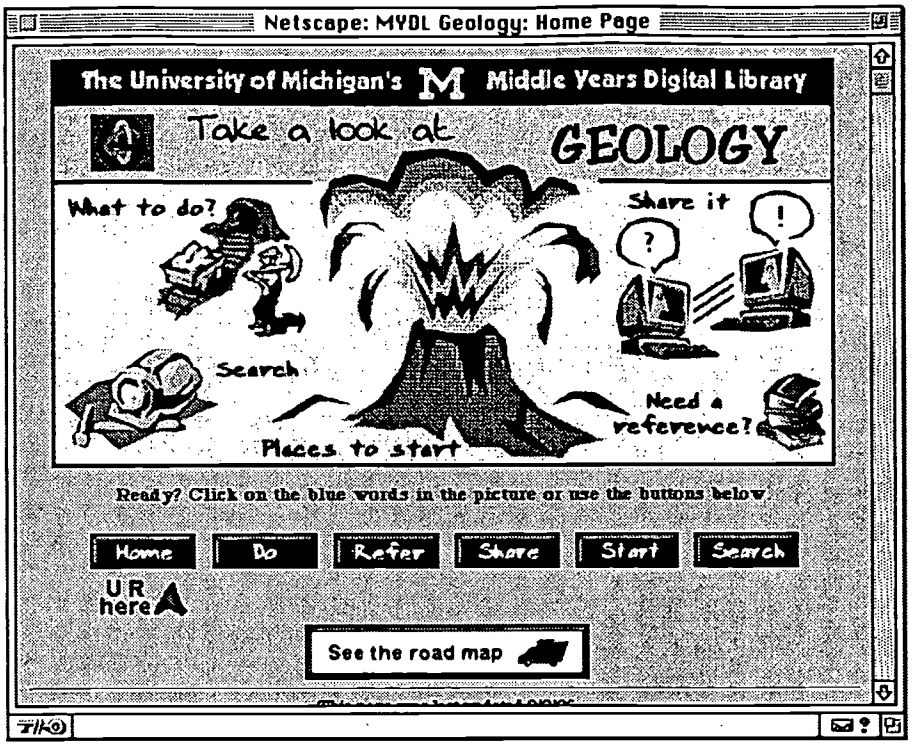

Figure 5. Middle Years Digital Library Geology Home Page

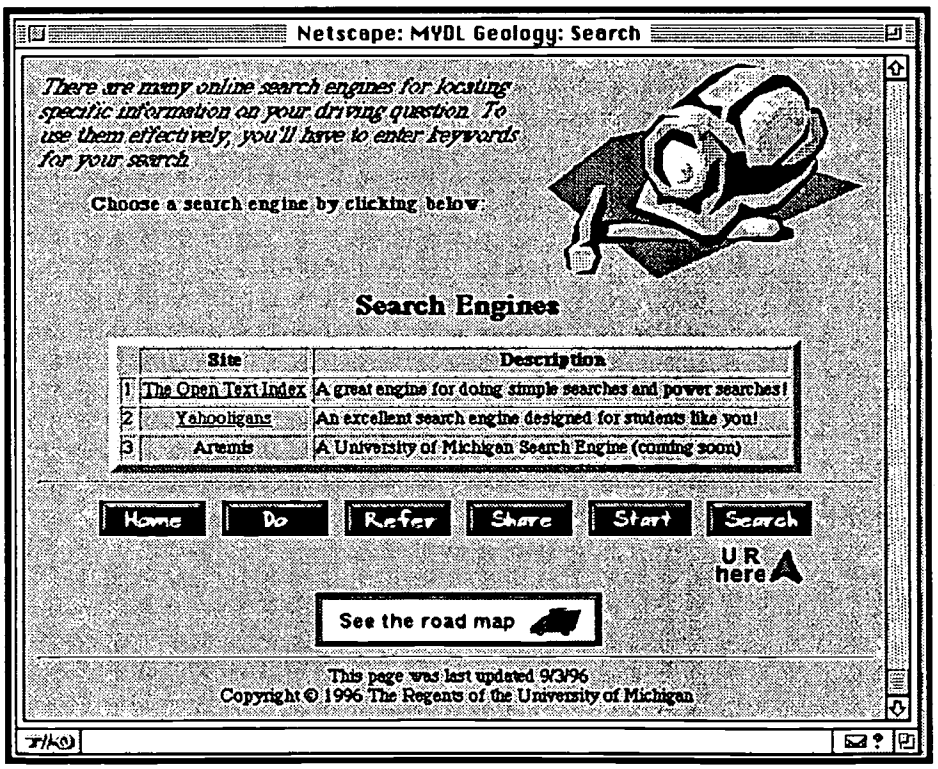

Figure 6. Navigation Bar and Location Cues

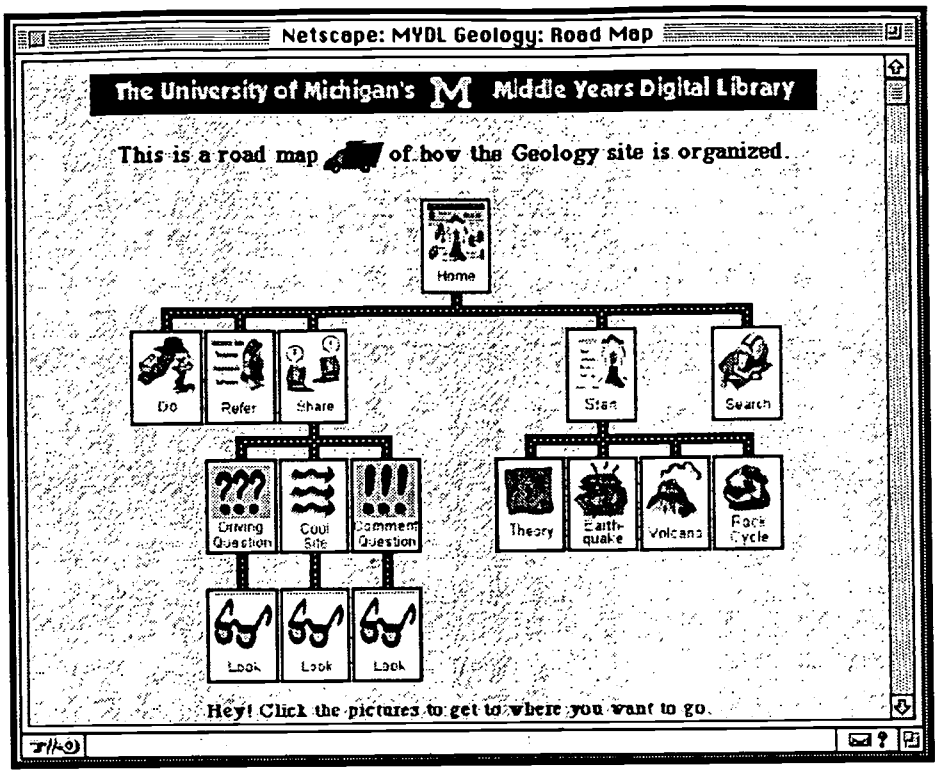

Figure 7. Site Map for Geology Unit

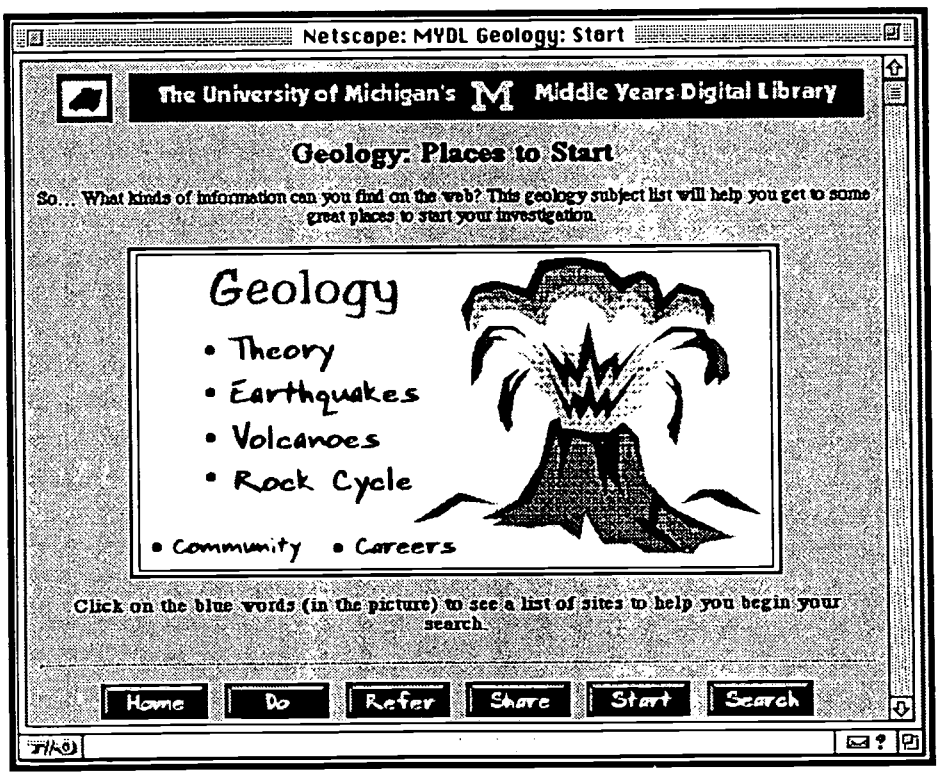

Figure 8. Organization of Geology Link Categories

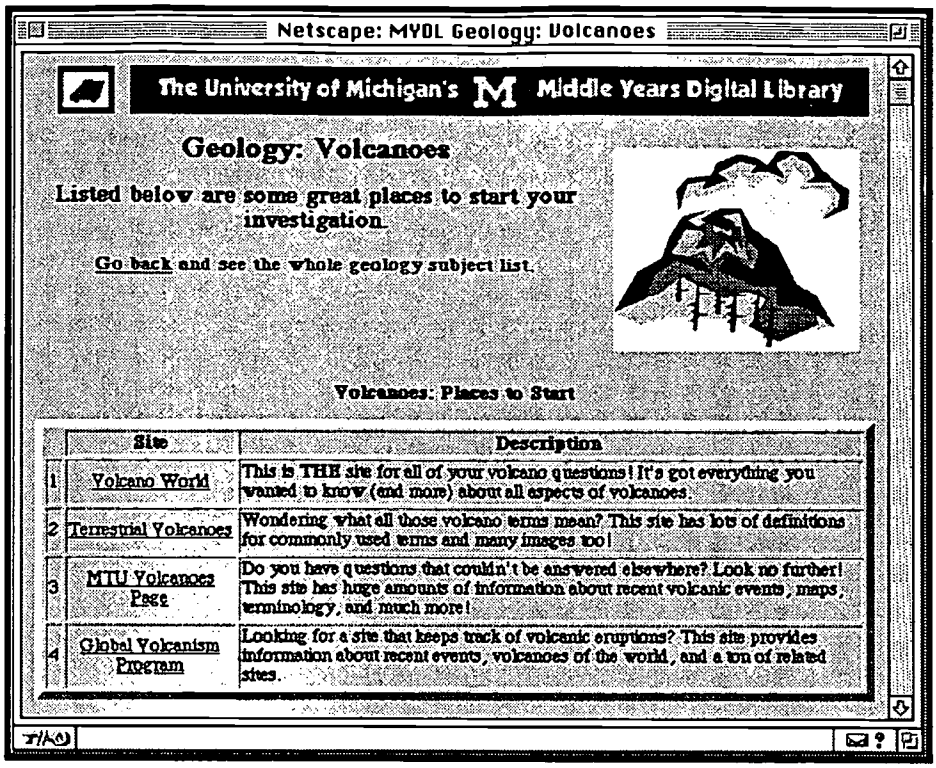

Figure 9. Organization of Age Appropriate Volcano Links

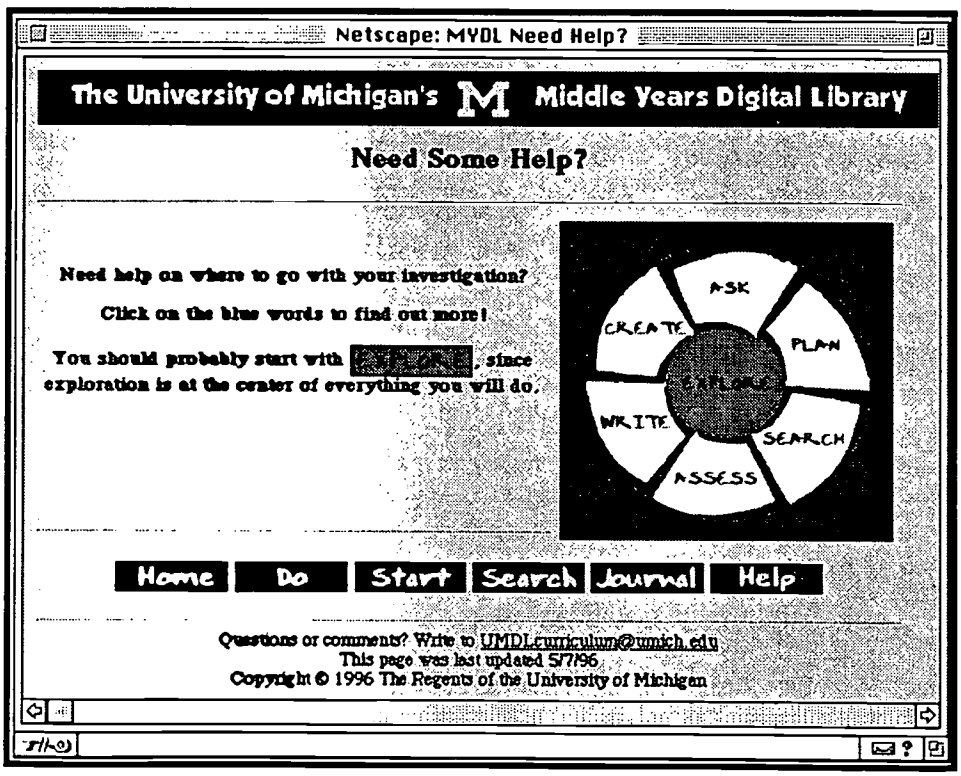

Figure 10. Investigation Wheel For On-Line Scaffolding

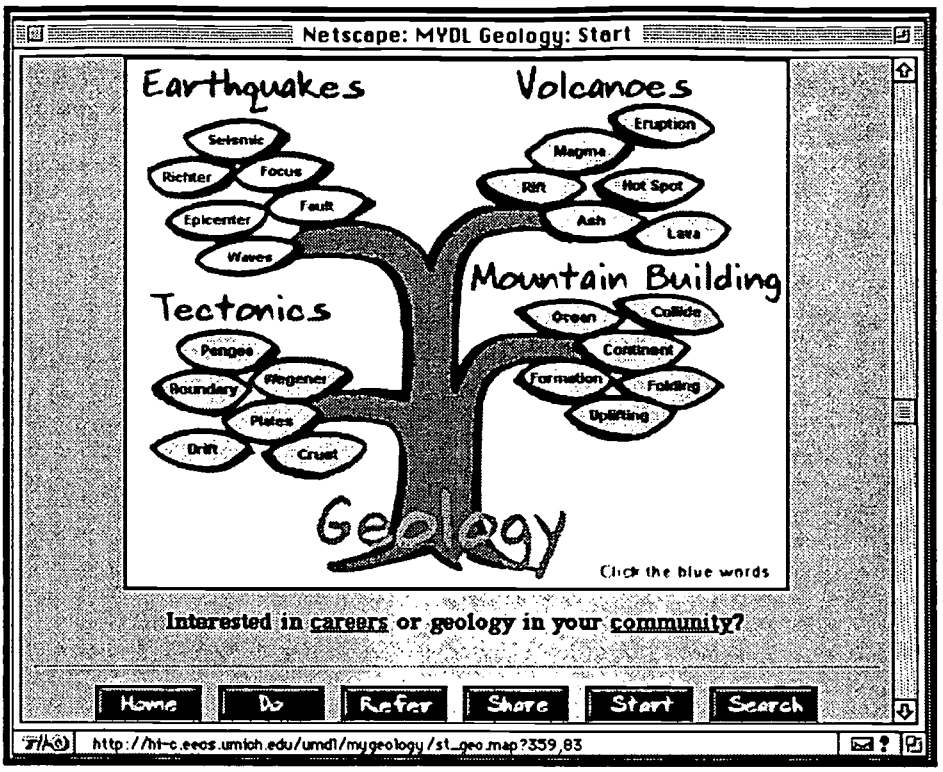

Figure 11. Hierarchical Subject Tree for Geology

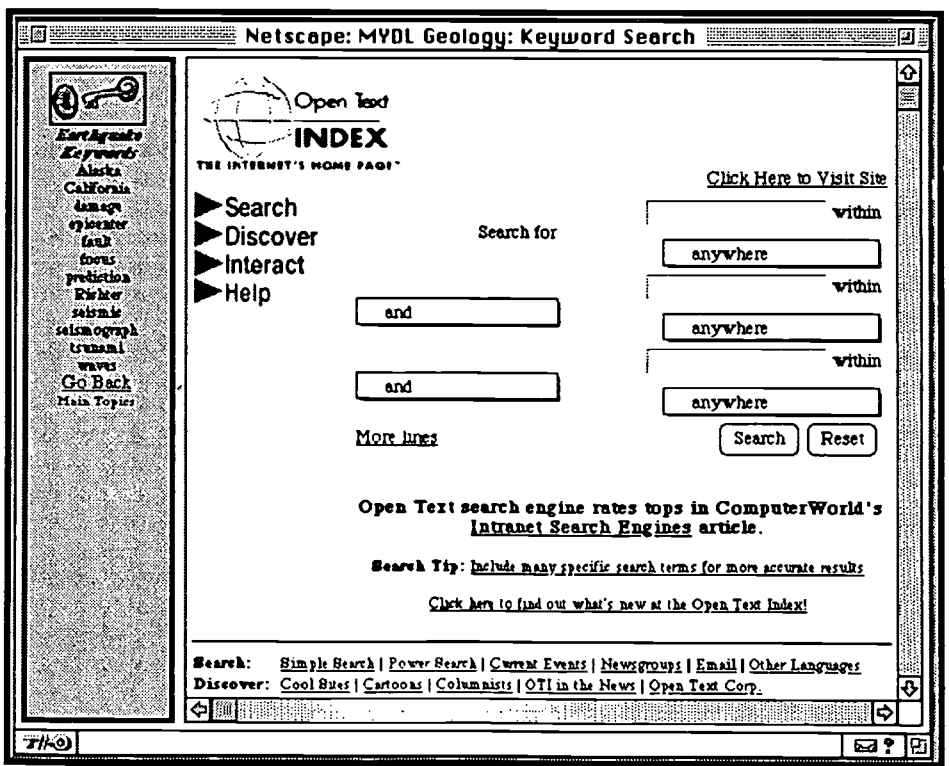

Figure 12. Keyword Help Support Frame

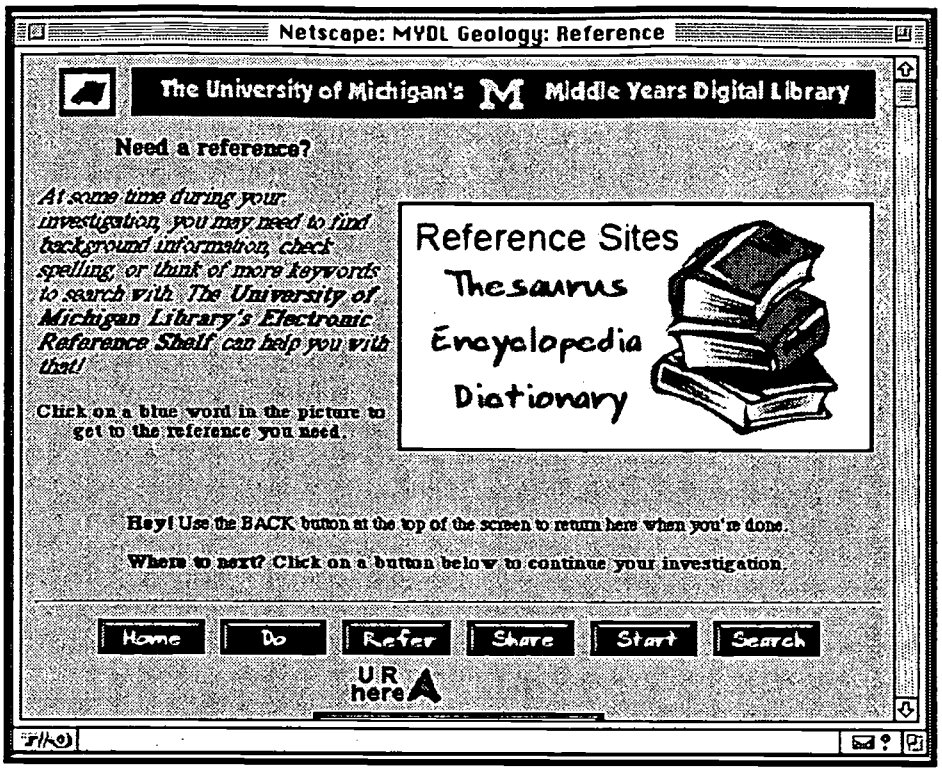

Figure 13. Reference Link Page

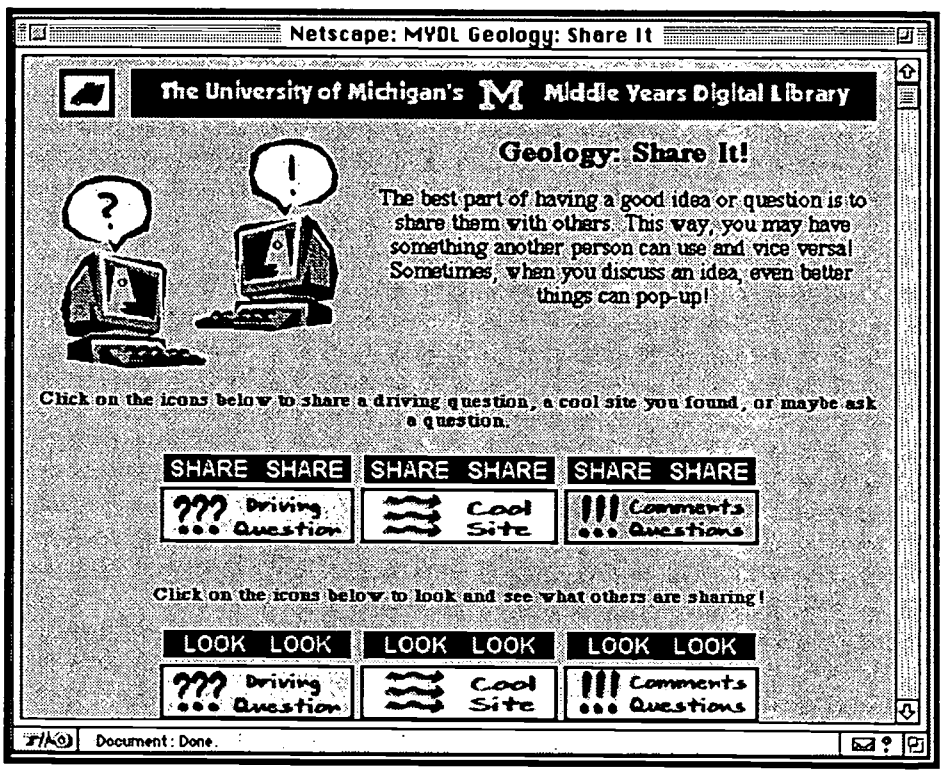

Figure 14. On-Line Sharing Page

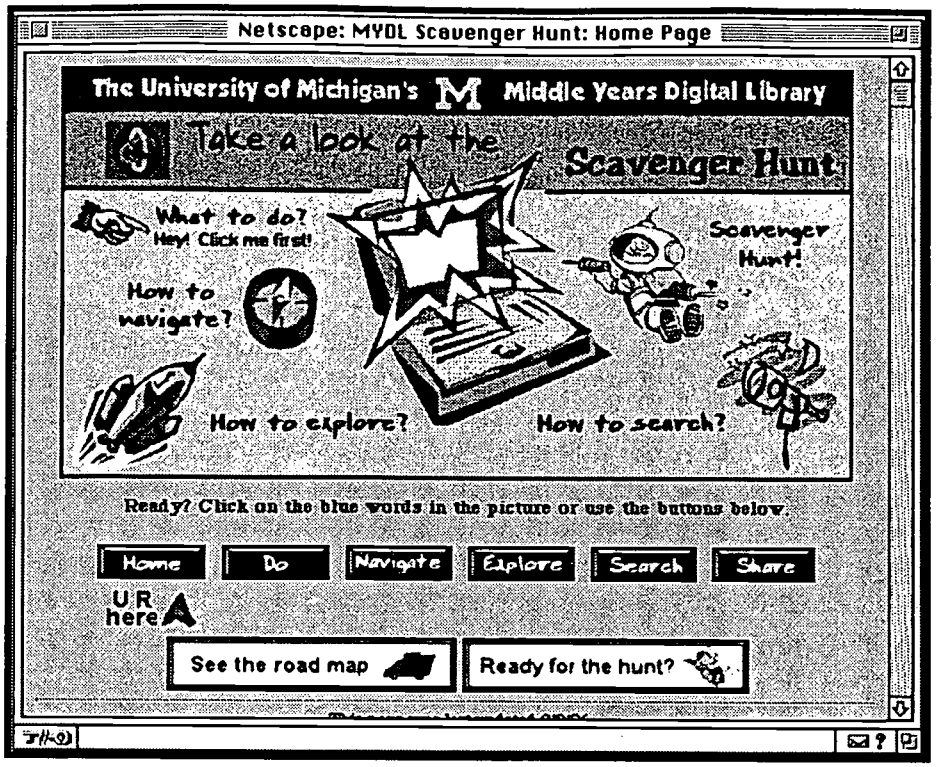

Figure 15. MYDL Scavenger Hunt Home Page

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