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ABSTRACT

The purpose of this study was to describe the depth and accuracy of sixth grade students' content understanding as a result of engaging in information seeking activities using Web-based resources in the University of Michigan's Digital Library. Eight student pairs received scaffolded pedagogical support from classroom teachers while completing four online inquiry units (astronomy, ecology, geology, weather) during a nine month period. Emerging understandings were assessed through a content analysis of learner final products and semi-structured interviews conducted during the school year. The analysis provided insight into both the depth (recalling information, offering explanations, articulating relationships, extending explanations) and accuracy of learner understandings (inaccurate, none, partial, accurate). Results of this study provide an empirical perspective on the use of World Wide Web resources in science classrooms. (Contains 66 references.) (Author/YDS)

Assessing the Nature of Learnersí Science Content Understandings as a Result of Utilizing On-line Resources

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Abstract

The purpose of this study was to describe the depth and accuracy of sixth grade studentsí content understandings as a result of engaging in information-seeking activities using Web-based resources in the University of Michiganís Digital Library. Eight student pairs received scaffolded pedagogical support from classroom teachers while completing four on-line inquiry units (astronomy, ecology, geology, weather) during a nine month period. Emerging understandings were assessed through a content analysis of learner final products and semi-structured interviews conducted during the school year. The analysis provided insight into both the depth (recalling information, offering explanations, articulating relationships, extending explanations) and accuracy of learner understandings (inaccurate, none, partial, accurate). Results of this study provide an empirical perspective on the use of World Wide Web resources in science classrooms.

Assessing the Nature of Learnerís Content Understandings as a Result of Utilizing On-line Resources

Educators in the 20th century have seen a number of technological innovations and the application of "newfangled tools" into science classrooms across the United States. Examples of these educational tools include filmstrip projectors, televisions, hand-held calculators, videotape cameras and players, and more recently the use of stand-alone, networked, and portable microcomputers. Advancements in the performance of microcomputers and associated software have allowed designers to construct simulations, lab interface apparatus, communication and collaboration tools, tutorials, and a variety of student assessment and evaluation materials. Although a number of these innovations have seen widespread implementation in classrooms, their appropriate application and impact on student learning continues to be a source of constant debate. The most recent innovation for classrooms, the use of the World Wide Web, offers yet another opportunity for enhancing the ways in which teachers teach and learners learn -- although this claim has been left largely unexamined.

The increased reliance on the World Wide Web for providing educational experiences to K-12 learners requires the immediate attention of the research community. Policy makers and educators are moving forward at a rapid pace to incorporate this resource in classrooms with little concrete guidance from theory on learning or empirical studies. Although a number of scholars have presented various arguments regarding its potential for learning, the literature falls short of providing substantial evidence to support their claims. For example, advocates (Barrie & Presti, 1996; Kinzie, Larsen, Burch, & Boker, 1996; Ryder & Graves, 1997) speak to the potential of the World Wide Web as an instructional tool for classrooms. General statements include: "The Internet and WWW provide us with the potential to change the nature of learning. We can use it to increase access to effective instructional materials in a variety of media." (Kinzie et al., 1996, p. 59); "Access to the Internet provides an opportunity to enhance studentsí reading and writing proficiency and to promote their skills in information gathering and problem solving." (Ryder & Graves, 1997, p. 244); "By its nature, the World Wide Web is a tool ideally and uniquely suited for the advancement of education." (Barrie & Presti, 1996, p. 371). Others imply more definitive possibilities: "Network collaborations, mentoring programs, access to supercomputers and instruments and, of course, access to the decentralized resources on the Internet, have enriched education." (Tinker & Haavind, 1997, p. 1)

However, while a large collection of literature speaks to the positive nature of the use of World Wide Web resources in science classrooms, other sources (Lookatch, 1995; Maddux, 1996; Winebrener, 1997; Stoll, 1998) remain pessimistic on its application as an instructional tool. Winebrener (1997) suggests "surfing the World Wide Web" is a "current educational panacea, bandwagon, magic bullet, fad..." and recommends educators "proceed with caution" before integrating it into the classroom. He describes how students can become mislead by viewing falsified information posted on the Web, frustrated due to an inability to locate specific information easily, and confused with varying forms of navigation found on individual pages. Winebrener (1997) describes his frustration with the lack of consistency in design and presentation of Web-based resources: "The Internet flies in the face of this philosophy [common principles of design]. Every site is unique with different buttons, dissimilar organization, unique paths to follow, and disparate information presented." (p. 21) Maddux (1996) supports these cautions and describes other problems related to the open-ended nature of the World Wide Web:

> ... it is intellectually appealing to think that hypermedia and open-ended exploration of data are more consistent with the way children think and learn than is linear exploration on which traditional print media is based. However, this assumption has yet to be verified through research, and I suspect that the truth is very much more complex than this. (p. 28)

Still others, maintain that research has been unable to prove using a computer or any other technology improves learning (Lookatch, 1995). In his critical assessment of educational technology studies, Lookatch makes a number of comments: "...[there is] a blind belief in a new and novel machine which students find more interesting and easier to accept than a talking head in front of the class." (p. 6); "There are no unique educational benefits from multimedia or its attributes." (p. 6); "multimedia is not the great equalizer. Access to technology is clearly inequitable and will continue to be for the foreseeable future." (p. 7). His harsh critique of educational technology is founded on a belief that a majority of current technology research contains inappropriate methodologies for controlling "a host of conditions that may account for the observed impact on learning." Lookatch (1995) suggests a teacherís pedagogical approach contributes to gains in student learning and achievement while the sole implementation of technology does not.

The complexity of these issues and messages continue to provide uncertain guidance to policy makers and educators who will continue to implement these tools in classrooms across the United States. Clearly, there is a need to broaden the scope of research with studentsí use of the World Wide Web and provide insight into its impact on teaching and learning. This research explored this learning environment through a year-long study of middle school learners as they engaged in information-seeking activities using on-line resources. Of importance were the content understandings that emerged as a result.

Study Rationale

Given the variety of literature for both positive aspects and challenges associated with using the World Wide Web in K-12 classrooms, it is critical to provide empirical evidence of its impact in schools. A number of instructional and learning questions beg empirical support: How does interaction with on-line resources impact student learning and understanding? How do learners make sense of information found on the Web? How do pedagogical practices influence the construction of understanding?

Early studies (Hoffman, 1997a; Hoffman, Kupperman, & Wallace, 1997; Lyons, Hoffman, Krajcik, & Soloway, 1997; Wallace, 1997; Wallace & Kupperman, 1997) conducted as part of the University of Michigan Digital Library and Middle Years Digital Library projects concluded students have difficulty locating and using resources in on-line environments. Specific challenges cited in their empirical studies were: Students have difficulty locating and taking advantage of information (Lyons et al., 1997; Wallace, 1997; Wallace and Kupperman, 1997), students often become lost and disoriented while navigating (Hoffman et al, 1997), students require a substantial amount of support to frame their activities (Hoffman et al., 1997; Lyons et al., 1997), students do not evaluate the resources they find (Wallace, 1997; Wallace & Kupperman, 1997), and students have difficulty using Web tools beyond basic operations (Wallace, 1997; Wallace and Kupperman, 1997). However, these studies were conducted over short periods of time (1 to 2 weeks) and utilized limited sources of data. This study utilized an extended perspective (4 units during the school year), a variety of data sources, and considered pedagogical influences to fully understand the dynamics of classroom teaching and learning with the World Wide Web. Using fine-grained data collection and analysis techniques, this research provides substantial insight into how learners construct understandings from on-line resources.

Research Questions

Based on this rationale, this year-long study focused on the effect of utilizing the Internet and World Wide Web as a technological tool to enhance student learning and content understanding. Using on-line resources as a means to support inquiry, it provided insight on the nature of learnersí science content understandings -- understandings that resulted from the processing of science facts, concepts, and processes demonstrated by a learnerís ability to explain their new conceptualizations, articulate it in problems or situations, and extend it to new or novel contexts. This study focuses on the following question: What is the nature of learnersí science content understandings as a result of utilizing on-line resources? To provide a more in-depth perspective on this study, two subquestions were drawn from this broad question:

1. What depth of content understanding (recalling information, offering explanations, articulating relationships, extending explanations) do learners possess and communicate as a result of utilizing on-line resources? To what extent are these made visible in learnersí products and conversations?

2. How accurate are the content understandings (inaccurate, none, partial, accurate) that learners possess and communicate as a result of utilizing on-line resources? To what extent are these made visible in learnersí products and conversations?

This research assists in lending evidence to questions regarding the value of the World Wide Web as a viable media for learning by providing an empirical perspective on studentsí emerging content understandings. Also, it builds upon previous studies and considers the impact of pedagogical factors in the analysis -- early studies failed to fully explore the influence these have on student learning. In addition, this study follows learners throughout the entire school year -- previous studies did not measure changes that could have occurred through the year. Most importantly, this study begins to provide support to theoretical claims made regarding the World Wide Web and the impact it has on teaching and learning.

Theoretical Underpinnings

The foundation of this study draws upon interwoven contexts framing the environment in which learners participated. Students engaged in on-line information-seeking activities, partnered with technological tools designed to support inquiry, and received substantial scaffolding. As a result, students were expected to develop new science content understandings. These can be framed with two contexts: conceptual and technological.

Conceptual Context:

A number of researchers describe information-seeking in electronic environments similar to the World Wide Web. These descriptions suggest information-seeking is a "special case of problem solving" (Marchionini, 1989) where learners recognize and interpret an information problem, establish a plan of search, conduct the search, evaluate the results, and "use" (Kuhlthau, 1993; Wallace, 1997) information to solve a problem. McNally & Kuhlthau (1994) describe how information-seeking consists of both undirected and highly directed activities -- undirected searching that leads to unexpected links, or discrepant events related to their topic, and highly directed searching for the purpose of finding specific information. They suggest students move through predictable stages (initiation, selection, exploration, formulation, collection, presentation) as they engage in these activities and claim students progress from "ambiguity to clarity, from seeking general information to seeking specific information." Kuhlthau (1993) describes how learners "construct their own points of view or understanding of a topic or problem" and increase their interest and confidence as they progress from initial conceptualizations of questions to the conclusion of the process.

In addition to information-seeking, a variety of literature (Nickerson, 1995; Perkins, Crismond, Simmons, & Unger, 1995; Perkins & Simmons, 1988; Talsma, 1997) defines the nature of science content understandings. Perkins & Simmons (1988) define content understanding as not only a recollection of facts and definitions associated with a particular subject area, but the utilization of mapping schemes to associate concepts with referents and strategies for memorization and recall (i.e. metacognitive strategies). A perspective of content understanding is further refined by Nickerson (1995) as a "matter of degree" that an individual understands something (i.e. concept, principle, structure, process) at a relatively deep level. These evidences include the ability of a learner to: explain to the satisfaction of an acknowledged expert, apply knowledge appropriately in various contexts, produce appropriate qualitative representations, make appropriate analogies, repair malfunctions, and predict the effects of change in structure or process. Talsma (1997) suggests that evidence of content understanding requires "more than producing verbal answers on cue" but instead involves transforming knowledge into "thoughtful understandings." She states: "...suppose that a learner can explain a concept in their own words, can exemplify its use in fresh contexts, can make analogies to novel situations, can generalize the law, recognizing other laws or principles with the same form, etc. When learners go beyond the information given, then we recognize that they can understand." (p. 2)

Perkins, et al. (1995) provides theoretical support for the complicated nature of knowledge construction by describing "outside" and "inside" understandings and the necessary cognitive resources learners must possess to develop these understandings. Outside understandings are made evident to others in terms of "overt behaviors" as learners communicate or act in three ways:

1. Offering Explanations. Displaying understandings by giving examples, highlighting critical features, and responding to new situations. Learners who simply present facts and describe phenomena without the ability to explain concepts, clearly lack understanding.

2. Articulating Richly Relational Knowledge. Expressing understandings with explanations constructed of knowledge linked from related aspects of a concept or phenomena and illustrating it in a single context. Learners who utilize sparse knowledge involving one simple rule would display poor understanding.

3. Displaying a Revisable and Extensible Web of Explanation. Demonstrating understanding by revising and extending explanations beyond the original source of information (i.e. textbook, lecture, video, experiment) to new contexts or situations. Learners who simply "parrot" explanations and cannot extend them to new contexts lack robust understanding.

Perkins et al. (1995) describe how these "outside" understandings, especially those tied to new contexts are frequently "fragile" and can grow or diminish in response to subsequent learning, discussion, or evidence.

The construction of "inside" understandings involve learners exploring a rich conceptual network described by Perkins et al. (1995) as an explanation structure: "A rich network of explanatory relationships that are encoded mentally in any of the many ways the mind has available -- through words, images, cases in point, anecdotes, formal principles, and so on." (p. 74) These structures, or "substrates" provide more than a memorized explanation as learners are able to extend and revise their understandings. Although some components of explanations may be "well rehearsed," other parts of the structure are "novel" and "created on the spot" permitting learners to extend their substrate. In addition to possessing a stable substrate on which to build new understandings, students require ongoing conceptual activities (i.e. conversation, exploration, instruction) to sustain active learning. In summary, Perkins et al. (1995) suggests explanation structures are not static, but expand as learners engage in topics and contract as they set topics aside, leaving new associations on the substrate to increase the likelihood of future reconstructions and extensions.

This study uses, in an exclusive sense, the perspective presented by Perkins et al. (1995). The notion of making depth of understanding public through explanation, articulation, and extension, provides a concrete method of classifying learners "outside" understandings. However, it is understood that these newly constructed understandings are fragile and are subject to modification based on new information and additional learning experiences.

Technological Context

A number of prominent scholars define the realm of technological tools for use in educative environments. These include early conceptualizations by Tinker (1978) describing how computers could be used for assisting students with data analysis, simulating laboratory experiments, and as a measurement processing instrument. More current literature suggests that interactive videodisks, telecommunications, microprocessor-based laboratories, and software applications for modeling, visualization, and simulating can "support learners as they solve complex and ambiguous problems by providing access to data and information, and opportunities to collaborate, investigate, and create representations." (Marx, Blumenfeld, Krajcik, & Soloway, 1997). Salomon, Perkins, & Globerson. (1991) claim these technologies have the potential to aid in cognitive or mental processing, can support intellectual performance, and enrich the minds of individuals. Pea (1985) refers to these computer tools as "cognitive tools" or "technologies of the mind." He suggests computer tools allow learners to accomplish certain tasks faster and with less effort, they can also redefine and restructure learning tasks. Bereiter & Scardamalia (1987) propose intellectual partnerships with technological tools can leave a cognitive residue in the form of a "generalized ability" for self-regulation and guidance.

In addition to these technological tools, a large body of literature describes the structure of hypermedia-based learning environments like the World Wide Web and theoretical advantages it has for learners. Conclin (1987) defines hypermedia as a method of building systems for organizing, structuring, and accessing information around a network of multimedia nodes connected together by links. These hypermedia systems permit the integration of text, graphics, audio, animation, and video into a "multidimensional learning environment" (Shepardson & Britsch, 1996). Salomon et al. (1991) suggest learners can develop "intellectual partnerships" with hypermedia-based programs as it "assumes part of the burden of information processing" as information is located, retrieved, and presented in a common format on the computer screen. Marchionini (1988) suggests hypermedia systems allow users to move "easily among vast quantities of information according to plan or serendipity" allowing freedom from the "linear, highly directed flow of printed text." Heller (1990) describes how hypermedia learning environments provide opportunities for the "exploration of alternatives" that can result in the "understanding of relationships that were previously unrecognized."

Browser software takes advantage of hypermedia design principles to make information easily accessible on the World Wide Web. Users simply click on text (hypertext), graphical buttons (icons), or images (image maps) to navigate through various networks, sites, and pages within sites in a non-linear manner. Through the utilization of these design principles, current browser software has enabled a wide range of users to access diverse sets of resources on the World Wide Web. The intuitive nature of this click and browse interface has certainly contributed to the popularity of the World Wide Web as a source for information retrieval.

A large body of literature (Gordin, Gomez, Pea, Fishman, 1996; Lea & Scardamalia, 1997; Linn, 1996) describes the theoretical advantages of using the World Wide Web for enhancing student learning. Linn (1996) suggests students can utilize the Internet as "a resource for developing a cohesive, linked, connected, and integrated understanding of science" (p. 34) when appropriately supported in knowledge building environments. Gordin et al. (1996) describes how the networked structure of the World Wide Web can "play a vital role in the formation and successful operation of learning communities." (p. 2) In addition, Lea & Scardamalia (1997) suggest specific Web-based collaborative and database tools can "support knowledge construction and progressive inquiry in a dynamic way." (p. 1)

In addition to the theoretical affordances hypermedia-based hold for learners, access to primary resources via networks provides unique opportunities for the construction of new understandings. A number of researchers (Barrie & Presti, 1996; Gordin, Gomez, Pea, & Fishman, 1996; Ryder & Graves, 1997; Tinker, 1996) have explored potential uses for the World Wide Web in science classrooms. Descriptions of these applications range from general accounts of broad activities to specific classifications of groups of resources. Barrie & Presti (1996) present three ways educators can utilize Web-based resources for instructional purposes: Providing both general and specific informational resources to students, incorporating the Web as an integrated interface for distance learning or "virtual classroom," and supplementing conventional content in the classroom. Ryder & Graves (1997) describe other applications: Utilizing the Web to access a broad range of information types in both textual and graphical formats, communicating with others via email, newsgroups, and live video, and obtaining instructional computer files and software. Tinker (1996) provides further insight and describes three classes of applications for supporting core mathematics and science educational goals: Accessing a diverse set of data and information that "no school could afford to acquire for its library," participating in "network-based communities" to promote student collaboration on projects, and obtaining on-line professional development materials for teachers. Other perspectives from Gordin et al. (1996) include three categories of recent applications of Web-based technology in K-12 learning situations: Accessing digital resources in the form of on-line libraries, museums, government information, curriculum and activities, and indices, collecting "raw data" and accessing a variety of analysis tools to assist with the interpretation of information gathered on-line, and collaborating between students and work-based learning communities.

Still others attempt to organize applications of the World Wide Web into more specific categories. Hoffman (1997b) suggests the Web has particular application in secondary science classrooms for: Collaboration and data sharing, distance learning, mentoring and tutoring, remote instrument control and data collection, virtual laboratory experiences, virtual field trip experiences, authoring and publishing, and research with primary sources. He suggests perhaps the greatest strength of the World Wide Web is the diverse range of primary resources available on-line from government (.gov) and educational (.edu) communities. These resources differ from other sources on the Web as they originate from major institutions, are often based on original or historical research and analysis, and can be interpreted as factual in nature. Students can take advantage of primary resources in a variety of ways. These include information gathering for research papers, reports, topic summaries, presentations, and other content-rich activities.

Wallace, Krajcik, & Soloway (1996) describe the benefits of Web-based resources (e.g. primary on-line resources) in terms of "characteristics" that are not necessarily unique to the World Wide Web, but are "quite different from the resources normally available in K-12 schools." These characteristics 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 orchestra halls), 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.

A variety of literature (Flake, 1996; Kay, 1996; Tinker, 1996a, 1997; Wallace et al., 1997) supports the use of primary sources on the World Wide Web for research-based activities. Wallace et al. (1997) in their study of Web-based digital libraries discuss the importance of students asking "personally meaningful questions" and engaging in information-seeking activities using digital resources. Tinker (1996a) describes how new technologies, like the Web, can support student inquiry because it "extends the capacity of students to undertake investigations" while accessing information resources. Flake (1996) discusses how students should be engaged in sense-making, problem solving, and open investigations using on-line resources, while developing skills for accessing knowledge.

A large segment of this study involves students utilizing primary resources for their information-seeking activities. The availability or non-availability of these resources have the potential to impact this study to a substantial degree. Primary resources having particular relevance to student questions may impact their capacity to engage in investigations. However, the likelihood of having primary resources available for all student topics and questions are slim -- how will learners respond when their question-asking is not supported by on-line resources?

In summary, this section provided a review of literature in respect to the contexts (conceptual, technological) that frame this study. Each of these contexts were critical to explore using current literature in an effort to establish a framework in this year-long study.

Learning Environment

The purpose of this study was to explore the nature of learnersí emerging content understandings within a framework of on-line inquiry through information-seeking. Students engaged in week-long investigations with the goal of developing a solution or answer to a question they have posed. The participants of this study were immersed in a learning environment designed to support question asking, resource gathering, and the construction of new understandings. This environment, designed by the University of Michigan includes a number of interrelated components: The University of Michiganís Digital Library, Artemis - The Interface to the Digital Library, Middle Years Digital Library - On-line Learning Materials, and Tactics and Strategies For Leading On-Line Investigations. Although explained individually below, they comprise a coherent whole for attempting to engage students (and teachers) in on-line inquiry.

The University of Michiganís Digital Library

The University of Michigan Digital Library (UMDL) Project is an ongoing effort of the Digital Libraries Initiative. The projectís goal is to create an architecture and software infrastructure for development of a digital library open to multiple heterogeneous collections. Wallace et al. (1998) describe how the structure and contents of the collections are "constrained only by their ability to communicate with an agent in the UMDL infrastructure about the contents, search protocols, and other technical information." (p. 1) Within the larger agent architecture, multiple smaller agents find information, negotiate prices for copyrighted information, browse collections, and register materials. Although the UMDL project currently includes test-bed earth and space science collections, other collections can be envisioned for specific user groups.

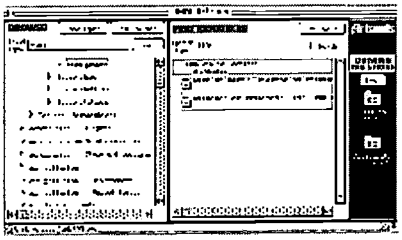
The UMDL collections for this study include a journal collection from UMI (Proquest Direct); a Web Collection (registered World Wide Web sites for 6th and 9th grade students), and a set of reference materials (Encyclopedia of Science and Technology, Grolierís Encyclopedia Americana, Websterís Dictionary, WordNet Dictionary/Thesaurus). The Web Collection consists of over 750 World Wide Web sites and pages identified by librarians as primary resources for middle and high school students in earth and space science classes. University librarians populated the Digital Library by locating, evaluating, and abstracting resources with both readable and appropriate content. In addition, librarians located resources that would take advantage of a Web-based environment -- those containing engaging content, high levels of interactivity, animated illustrations, and on-line forms for communicating to Web authors. These sites are registered in the UMDL using a controlled vocabulary permitting students to initiate searches for accessing the collections.

Students used the University of Michiganís Digital Library during the course of this study to access digital resources related to their questions. This environment hoped to provide a concise set of collections that stand in contrast to those utilized in previous studies (Lyons, Hoffman, Krajcik, & Soloway, 1997; Wallace, 1997; Wallace & Kupperman, 1997). These early studies permitted students to access resources from the entire World Wide Web -- and they were often unsuccessful in attempts to locate appropriate materials for their investigations. It was expected the UMDL had a potential to influence the degree to which students engage in information-seeking activities and the content understandings they develop as a result of using organized, age-appropriate collections.

Artemis - The Interface to the Digital Library

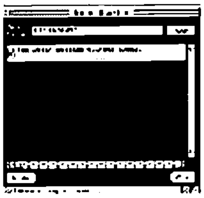
A major component of this study was student interaction with Artemis (Figure 1), a Java-based interface to the UMDL accessible from the World Wide Web. This interface was designed to provide specific cognitive support for learners as they engage in information-seeking activities (Wallace et al., 1998). Artemis allows students to focus on the task of inquiry rather than concerning themselves with organizing their workspace, recalling pass searches and sites, and recording addresses of useful sites.

Figure 1. Artemis Interface Main Screen



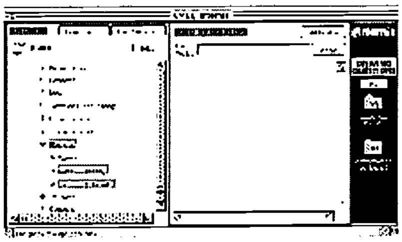
Driving Question folders (Figure 2) provide support by encouraging students to reflect on useful sites they find (as well as their question) before placing the resources in folders.

Figure 2. Artemis Driving Question Folder



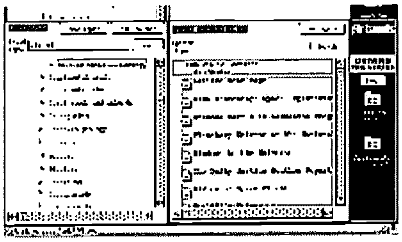
Broad Topics (Figure 3) provide support by helping students generate keywords, recall prior knowledge, and view structures of a particular content areas before initiating queries to the Digital Library.

Figure 3. Artemis Broad Topics List



Collections (Figure 4) also support students by providing useful resources pertinent to their Driving Question. This allows students to focus on the contents of the resource, evaluate its usefulness, and synthesize information rather than spending the majority of time simply locating appropriate sites on the World Wide Web (Hoffman, Kupperman, & Wallace, 1997; Lyons, Hoffman, Krajcik, & Soloway, 1997; Wallace, 1997; Wallace & Kupperman, 1997).

Figure 4. Artemis Collections



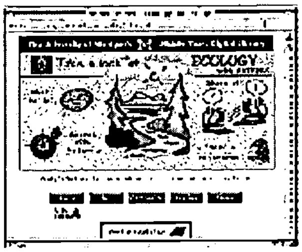
Students used Artemis as an exclusive interface for accessing the University of Michiganís Digital Library during the study. This environment provided the scaffolding learners required for asking questions, searching for information, and accessing age appropriate collections related to their investigations. Early studies (Lyons, Hoffman, Krajcik, & Soloway, 1997; Wallace, 1997; Wallace & Kupperman, 1997) did not utilize Artemis -- students used commercially available on-line search engines for locating resources. As a result, they were often unsuccessful locating information they could use for their research. It was anticipated that Artemis had the potential to influence the degree to which students engaged in information-seeking activities.

Middle Years Digital Library - On-line Learning Materials

The Middle Years Digital Library (MYDL) project is a subset of the UMDL project. It focuses on providing printed and on-line learning materials to support student inquiry on the World Wide Web. Students utilize these materials as a tool to support their information-seeking activities as they ask question of interest, plan their inquiry, search for information, assess their findings, and create rich representations of their newly constructed understandings. The MYDL project offers a number of on-line physical science units for use by teachers and students including astronomy, ecology, geology, and weather. An additional unit, the Scavenger Hunt, is designed to help learners who are new to using Artemis, the UMDL, and navigating the World Wide Web.

Hoffman (1997) describes the iterative nature of design for these on-line learning materials and specific features supporting student inquiry on the World Wide Web. These materials include a Home Page (Figure 5) where students begin their investigation, a Road Map that provides an outline view of the major sections of the MYDL site, a What to Do page that gives a brief introduction to the science unit and the inquiry process. A References page that allows students to reach the University of Michiganís on-line thesaurus, encyclopedia, and dictionary, a link to Artemis that permits access to the UMDL, and a Share page that allows students to click individual icons to reach on-line forms for sharing Driving Questions, sites pertinent to their questions, and comments or questions to other students.

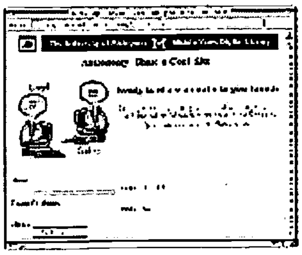
Figure 5. MYDL Ecology Home Page



The design goal of MYDL on-line learning materials is to provide a common framework for learners as they participate in information-seeking activities across a number of content areas. Hoffman (1997a) describes how general design, navigation, content/context, interactivity, and standardization features in the design enhance the usability and consistency of these materials. 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 efforts to create materials which could be part inquiry activities, 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 on-line inquiry and utilize 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.

An example of a powerful feature in the MYDL on-line learning materials is the ability of students to share and immediately post sites (called cool sites) they find valuable to their inquiry. Previous iterations of MYDL materials 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 (Figure 6), which automatically posted reviews of sites to a Web page where students could view each others critiques and ideas.

Figure 6. MYDL On-line Sharing Form



In addition, more detailed information about the critiqued site is available for student review. Hoffman (1997a) suggested students might benefit from sharing their ideas and information with others on-line. 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, Blumenfeld, Marx, & Soloway (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 work in a public forum such as the Web.

Students used the Middle Years Digital Libraryís on-line learning materials as an integral component of their information-seeking activities. This provided an environment to gain a visual context for their on-line inquiry, share Driving Questions, sites, comments, and questions, and obtain access to Artemis. Previous MYDL studies used earlier versions of these on-line materials, but they have been redesigned to accommodate Artemis and include a number of other improvements.

Pedagogical Supports

In addition to the learning environment, this study is also impacted, to a large degree, by the pedagogical supports provided to learners. Previous MYDL studies did not provide a substantial amount of guidance for students, although a number of sessions were conducted with teachers discussing the MYDL pedagogical model. In each study, researchers observed that students did not fully engage with on-line inquiry. This study recognizes the importance of communicating a comprehensive pedagogical model to teachers and students in an effort to promote a high degree of participation and thoughtfulness with inquiry-based learning. This section describes how a set of pedagogical principles provided guidance for learners as they engaged in inquiry through information-seeking during this study.

Early studies (Hoffman, 1997a; Lyons, Hoffman, Krajcik & Soloway, 1997; Wallace & Kupperman, 1997) speak to the challenges of implementing materials that support students pursuing inquiry-based activities on the Web. Early research efforts by Wallace and Kupperman (1997) show a mismatch between the intended goals of the project and behaviors of students as they engage in on-line investigations. From the analysis of data, four themes emerged: "1. Students donít explore much. 2. Students tend to seek answers rather than aim for understanding. 3. Students donít evaluate sources: they receive content from on-line sources at face value. 4. Students learn to use Web tools easily, but use them naively." (p. 12). Based on this feedback, the MYDL project investigated the dynamics that occurred between teacher and student, student and student, and student and computer. They concluded that one factor influencing a studentis actions during on-line sessions was the pedagogical approach employed by the teacher and corresponding degree of support received during the inquiry units, both on and off-line.

In an effort to improve the success of student information-seeking activities, the MYDL project developed a series of print-based scaffolding materials to support students (and teachers) during on-line units. Tactics and Strategies For Leading On-Line Investigations (Hoffman & Eccleston, 1997) is a series of booklets providing guidance for teachers who are new to the Web or unfamiliar supporting student-led inquiry. In addition, it contains age and reading level appropriate activity sheets for students to use that provide a process model for scaffolding strategies for inquiry (asking, planning, searching, assessing, writing, creating). More specifically, these pedagogical support materials included:

1. Introduction. This section describes the University of Michiganís Digital Library project, the range of people and organizations that can participate in an on-line inquiry unit, how the MYDL project utilizes technology, and suggestions for using the Tactics and Strategies manual with students. This information assists in providing teachers with a strong foundation of the developmental background of UMDL-MYDL projects, and how they can begin to incorporate student-led inquiry into the classroom.

2. Investigating on the World Wide Web. This section presents an overview of the conceptual nature of on-line inquiry, a description of the Investigation Wheel (Figure 7) -- a graphic used to represent various stages of the inquiry process, and suggests ways in which teachers can support students. These teacher-based pages provide of general information-seeking strategies (inquiry strategies) students utilize as they engage in inquiry with on-line resources. In addition, this section introduces specific pedagogical practices to support students during these activities.

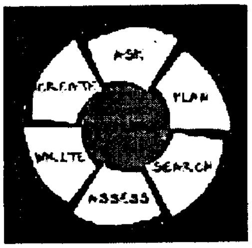
3. About the MYDL Science Units. This section lists the main goals of a MYDL science unit, describes how students will take advantage of on-line materials, and suggests a specific unit option depending on the experience of students. These pages are designed to provide initial guidance for teachers as they begin to plan and implement MYDL on-line and print-based materials with students.

4. Day-by-Day Plans. This section details specific daily plans, associated activities, and recommended assessments for students. It provides specific teacher interventions for supporting students at all stages of their inquiry. This information serves as pedagogical support for teachers and assists in their instatiation of inquiry-based learning into their classrooms.

5. Student Activity Sheets. This section contains student oriented activity sheets to support learners as they ask questions, plan inquiry activities, search the Digital Library, assess search results, share information on-line, create products, and use MYDL on-line materials. These activity sheets provide explicit scaffolding to guide students during all phases of their on-line inquiry.

6. Appendix. This section provides a glossary of Internet terms, options for student products, an evaluation rubric, student Internet contract, and information about the Teaching and Learning Group at the University of Michigan.

Figure 7. MYDL Investigation Wheel

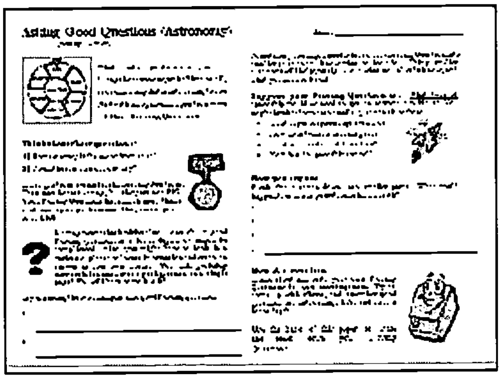


Research on the use of scaffolding to support the learning process has been well researched and documented (Palinscar & Brown, 1984; Paris, Wixson, & Palinscar, 1986; Rosenshine & Meister, 1992; Wood, Burner, & Ross, 1976). Scaffolding can be viewed as a process of providing decreasing amounts of support to help students "bridge the gap between their current abilities and the intended goal of instruction." (Rosenshine & Meister, 1992, p. 26). Other definitions include a reference to instructional strategies that are both temporary and adjustable that allow learners "to participate at ever-increasing levels of competence." (Palincsar & Brown, 1984, p. 122). An additional perspective describes scaffolding as "a process that enables a child or novice to solve a problem, carry out a task, or achieve a goal which would be beyond his [or her] unassisted efforts (Graves et al., 1996, p. 90)." Scaffolding materials appear in many forms ranging from print-based materials to modeling behaviors enacted by the teacher. Rosenshine & Meister (1992) cite that scaffolds can be applied to the teaching of all types of skills and are "often indispensable" for teaching high-level cognitive strategies with steps or procedures that are difficult to specify.

These scaffolding materials or procedures often begin with simple exercises that allow learners to participate in a difficult tasks or activities early on in their inquiry. Through a series of closely monitored steps, difficulty is gradually increased as students become more involved with their learning, and finally the support by the teacher is withdrawn. This scaffolded instruction allows students to gain appropriate experiences and skills to increase their cognitive capabilities toward the task.

The intention of MYDL Tactics and Strategies materials were to provide this type of scaffolding so students could learn inquiry strategies and become successful at asking broad questions and pursuing their topics using digital resources on the World Wide Web. For example, students often have difficulty developing good "Driving Questions" broad enough and worthy of a sustained investigation over the period of a few days. Questions like: "Where is the coldest place on earth?" can limit the student to a single response while "Why is Antarctica the coldest place on earth" provides for a more rich investigation and response. The activity sheet, Asking Good Driving Questions (Figure 8), demonstrates the use of scaffolding as it provides poor examples of Driving Questions, describes the attributes of appropriate questions, and prompts students to change poor questions into good ones. In addition, this print-based scaffolding sheet describes how to take a broad Driving Question and divide it into smaller segments to ease the task of locating information. Finally, the activity requires students develop three possible Driving Questions for their inquiry.

Figure 8. Asking Good Driving Questions Activity Sheet



Asking Good Questions (Astronomy)

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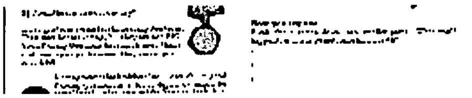
However, print-based materials alone do not guarantee students will develop enhanced inquiry skills as teachers play a substantial role in the scaffolding process. Rosenshine & Meister (1992) discuss that scaffolding often includes a substantial amount of teacher modeling, discussion, prompts, guidance, regulation, and feedback to be effective. These additional scaffolds provide the support and reinforcement students require as they move toward cognitive growth.

To help visualize the process students and teachers engage in during a typical MYDL unit, the following describes the activities for a first content unit that follows the MYDL Scavenger Hunt.

1. Before Session 1- Getting Ready. The teacher spends two or three periods preparing students for the inquiry unit by discussing current issues to build interest, presenting project goals, and stating assessment issues. Students complete an activity sheet "The Investigation Wheel" introducing the inquiry process (ask, plan, search, assess, write, create) and develop initial Driving Questions with support from "Asking Good Questions."



ete the activity sheet "Using the Road Map" while on-line to become familiar with the contents of the MYDL MYDL site and critique the questions of their peers. The teacher supports students while on-line and leads a

3. Session 2 - Planning the Investigation. The teacher leads a discussion to assist students in planning their inquiry. The activity sheet "Planning Your Investigation" prompts students to think through their timeline, and what sources they may require for their Driving Question. In addition, students create Driving Question folders in Artemis and begin to browse the Digital Library for resources.

4. Session 3 - Browsing with Artemis. Students use Artemis to browse the Digital Library for resources, collecting initial information for their question. Students may refine their Driving Question to better focus their efforts during on-line sessions. The teacher provides extensive support during this phase of inquiry, and discusses the availability and quality of information available for student questions.

5. Session 4 - Searching with Artemis. Students become more focused with searches, locating sources that will help provide a solution to their question. In addition, they begin to synthesize information and formulate new understandings. The teacher continues to provide support by helping students utilize Artemis to locate appropriate sources of information.

6. Session 5 - Searching with Artemis. This dayís activities are similar to Session 4.

7. Session 6 - Sharing and Critiquing. Students complete the "Sharing a Cool Site" activity sheet and post a favorite site they found useful during their on-line inquiry. Students complete their work on-line by critiquing sites posted by their peers. The teacher supports students as they post and critique sites.

8. After Session 6 - Creating and Evaluating. Students build a product or artifact representing their newly constructed understandings (i.e. pamphlet, poster, newscast) and may conduct a short presentation for the class. The teacher evaluates student artifacts utilizing a rubric discussed with students at the start of the project.

Although this sequence of activities represent the ideal case, it is understood that teachers responded differently to student needs and made appropriate adjustments. However, these print-based support materials provided a starting point where novice teachers could become familiar with MYDL pedagogy and make progress toward implementing student-led inquiry in their classrooms.

This study provides a fine-grained perspective on the emerging science content understandings of learners as a result of their inquiry. The past section described the pedagogical supports for this study, initially speaking to the challenges associated with implementing inquiry-based learning using resources from the World Wide Web. Using these challenges as a basis, an extensive suite of tools and resources were developed to provide specific support for fostering student-led inquiry. It was anticipated these materials would provide the support students required to become competent in participating in various phases of information-seeking activities.

Methodology

The challenge of attempting to understand the impact of the use of technological tools for inquiry-based, information-seeking activities in on-line environments required a comprehensive research methodology. This methodology expands both the approach and scope of early studies conducted as part of the MYDL project in an effort to obtain a more fine-grain perspective of student emerging inquiry strategies and content understandings. To gain insight into the research question, a variety of data sources, data collection methods, and analysis techniques were utilized. This section describes the setting, participants, technological tools, tasks, data collection methods, and analysis techniques of the study. The outcome of this studyís analysis is to provide both qualitative and quantitative support for describing the range of content understandings students developed as a result of their information-seeking activities. These descriptions provide specific conclusions related to depth of understanding (recall, explain, articulate, extend) and accuracy of understanding (accurate, partial, none, incorrect).

Research Setting

Student participants for this study were enrolled in six grade classrooms at a middle school located in a medium-sized midwestern city, serving approximately 830 students and employing 40 full-time equivalent teachers. The school draws students from a majority of middle class, and upper-middle class families, with a wide range of educational backgrounds. While some parents have advanced graduate degrees (Ph.D., M.D.), other parents have not completed high school. It is estimated that 35 percent of parents have blue-collar jobs, and 65 percent have white-collar or professional careers. 20 percent of students qualify for free or reduced breakfast and lunch at school. The ethnic diversity of the school is estimated at 80 percent Caucasian, 16 percent African-American, and a 4 percent mixture of other groups.

The school operates from a modified middle school model where teams of two teachers work with a single group of students for each of their four academic subjects, but the curriculum is traditional in terms of its coverage and delivery. Typical students move from class to class for seven periods during the day, but remain together as a group for mathematics, science, social studies, social studies, language arts, and content area reading. The remaining period of the day is an elective, where students choose computers, foreign language, industrial technology, music exploratory, band, orchestra, choir, or physical education. In total, the average sixth grade student sees four or five different teachers each day.

This middle school contains two computer classrooms (lab) located in the media center, with one dedicated for MYDL and other University of Michigan work. Although the classroom is rather small, it accommodates 15 student pairs on computers. All computers are Power Macintosh 5260/100 with 13 inch color monitors, wired to the Internet via an ISDN line. In addition to the computers, a single low capacity laser printer is available to students. Downloads and uploads between student computers and Internet Web sites are normally accomplished in a few second or less, except for peak usage periods during the day when transfer times can be extended to 15 seconds or more. Overall, the computer classroom was adequate for the participants and data collection.

The University of Michigan has a long history of collaboration with this district and this middle school, and the setting was adequate for this study. The school provided unlimited access to teachers, students, the computer classroom, and other facilities. As a result, this cooperative nature and willingness to participate allowed a rich set of data to be collected.

Research Participants: Teachers

Two teachers participated in this study. Nanci, the first teacher, had ten years experience teaching mathematics, science, geography, and foreign language at the middle school level. Her assignment for the length of the study was teaching sixth grade mathematics and science. Nanci has a Bachelors of Arts degree with teaching certification in mathematics and science, and a Masters of Arts degree in middle school curriculum, and continues to enrich her education in mathematics and science through the participation in summer institutes. Nanci also is involved in a number of extra-curricular activities including coaching instructional swimming, synchronized swimming, and life-guarding. In addition, she is a leader-facilitator for the districtís sixth grade mathematics curriculum, a co-curriculum leader for her schoolís mathematics program, and performs consulting outside the district for mathematics curriculum development. Nanci had participated in the Middle Years Digital Library project for three years, and had used a number of on-line and print-based materials with her students. During this time, she provided substantial feedback regarding the design and integration of University of Michigan curricular materials into middle school classrooms.

The second teacher who participated in this study, Heather, had three years experience teaching language arts, science, and geography at the middle school level, and three years teaching at a Montessori school. Her assignment during this study was teaching sixth grade science. Heather has a Bachelors of Arts degree in psychology and English, is certified to teach general science and language arts, and continues to enrich her education in psychology and science through participation in summer institutes. Heather also is involved in a number of extra-curricular activities including Science Olympiad, ski club, and after school tutoring. Heather has participated in the Middle Years Digital Library project for two years, and has used a number of on-line and print-based materials with her students. During this time, she provided feedback regarding the design and integration of Artemis, the interface to the University of Michigan Digital Library into middle school classrooms.

Research Participants: Students

Eight pairs of sixth grade science students were selected for this study, four pairs from Nancií s class and 4 pairs from Heatherís class. These students were selected based on the following criteria:

1. Mixed gender. Participants from mixed gender backgrounds provided data to gain insight on the subtleties of male and female engagement with the construction of content understandings.

2. Mixed ethnic background. Similar to gender issues, participants from varied ethnic backgrounds provided a cultural perspective on the issues related to this study.

3. Average to above average ability. Previous studies with MYDL materials utilized participants at low to middle levels of ability, resulting in limited insight on the impact of on-line resources in science classrooms. This study focused on the impact of these materials on ability groupings at a slightly higher level.

4. Good communication skills. Participants had a tendency to be average or above average communicators, allowing for the maximum possible insight into thinking during on-line sessions and interviews.

5. Willingness to work cooperatively for the entire school year. Since this was a study covering the entire school year, participants agreed to work together for the duration of this study.

Table 1 describes Heatherís and Nanciís students who participated in this study. In addition to the pair number and pseudonym, it contains information on learnersí gender and ethnicity.

Table 1

Student Participants

Pair	Student Name	Gender	Ethnicity
Heatherís Students			
1	Brett	M	European-American
	Cedric	M	African-American
2	Edward	M	European-American
	Kevin	M	Asian-American
3	Angela	F	European-American
	Jamie	F	Asian-American
4	Brad	M	European-American
	Gabe	M	European-American
Nanciís Students			
5	Britt	M	European-American
	Tanya	M	African-American
6	Kurt	M	European-American
	Mike	M	European-American
7	Grant	F	Indian-American
	Robert	F	European-American
8	Brooke	M	African-American
	Karley	M	European-American

Note: Teacher and student names are pseudonyms.

The number and diversity of participants was an advantage in this study. The district and school are familiar and accepting of university projects and recognize the mutual benefit they have for students. Teachers had extensive experience facilitating university sponsored projects, and possessed the expertise to integrate MYDL pedagogical practices into their classrooms. Middle school students at this grade level were open to trying new activities and often excited by the prospect of talking to other (teachers, parents, researchers) about their learning. In summary, the range of participants provided a rich source of data for this study.

Participant Activities

This study involved students utilizing the MYDL Scavenger Hunt and four MYDL content units (astronomy, ecology, geology, or weather) during the school year. The Scavenger Hunt, a tutorial-like set of Web pages, is designed as a sequential five day introductory unit to help students become familiar with navigation, exploration, and Artemis, the interface to the Digital Library. A series of pages encourages users to interact and become familiar with hypertext, icon, and image map navigational tools on the World Wide Web. In addition, students interact with Artemis to create Driving Question folders, perform simple searches, and locate specific information on a topic of their choice. Subsequent content units provided a series of on-line materials for students to use as they investigated questions related to specific topic areas. Pages included a description of the assignment, a link to the Artemis interface, and provisions for sharing and viewing Driving Questions, sites of interest, and comments or questions.

These four content units closely matched the sixth grade science curriculum for the participating middle school and entire district. Modeled after the National Science Education Standards by the National Research Council (1996), the districtís sixth grade science curriculum consists of four, ten week units covering astronomy, ecology, geology, and weather. Each of these units had a defined set of objectives, activities, and assessments teachers and students were expected to complete during the 10 week period. One requirement involved undertaking a research project, which has been enacted by engaging students in an inquiry-based MYDL unit. This replacement for a traditional "book report" has been accepted by the district -- the MYDL units were continued for all middle schools for the school year.

Teachers cooperating in this study utilized the inquiry-based pedagogy outlined in the *Tactics and Strategies for Leading On-line Investigations* manual as a basis for implementation with students. Described earlier, this manual provided specific scaffolding for students during each phase of their inquiry by providing activity sheets with directions, suggestions, questions, and writing prompts. These scaffolds were built upon as the year progressed with the intention of removing a number of them as students become more proficient at various components of inquiry. However, teachers had the freedom to modify and adjust this pedagogy to suit their individual teaching styles and the needs of their students. It was not the intention of this study to force a particular pedagogical framework on teachers, but instead to allow them to use principles and ideas from the model to assimilate it into their classroom practices.

Data Sources

A variety of data sources were used during this study, focusing on the nature of their emerging content understandings. Four types of data sources were utilized: 1) Process Video for gaining insight into student content discussions while on-line and resources they used, 2) Student artifacts for determining how in-process and final understandings were represented, 3) Semi-structured interviews for obtaining in-depth perspectives of content understandings, and 4) Classroom-lab video for determining the influence of pedagogical practices on studentsí construction of understanding.

Process Video

Information about the studentís activity on-line (e.g. conversations, use of resources) was gathered with a technique called Process Video (Krajcik, Simmons, & Lunetta, 1988; Stratford, 1996; Lyons & Hoffman, 1997). Lyons & Hoffman (1997) describe this process where a computer monitor signal is fed to a converter module that changes the information to a standard television signal. This television signal is sent to a high quality video recorder (Hi8 VCR), where the studentsí screen activity is recorded on tape. In addition, each student wears a microphone, and the audio signal is increased with a mixer/amplifier, and sent to the video recorder where it is saved on the audio track of the tape. This technique allows the researcher to both view screen activity and hear conversations of students while they work with computer on-line. Process Video was collected for each student pair during all on-line sessions. In total, this study collected 184 sessions of process video tapes, averaging 35 minutes each. These tapes provided a rich source of data, allowing detailed insight into student conversations and use of on-line resources when engaging in information-seeking activities. In addition, Process Video captured a fine level of detail that was not possible with field observations or ambient classroom video.

Artifacts

A variety of artifacts were collected from students after each unit -- completed MYDL activity sheets, on-line postings, final products (i.e. posters, reports, videotapes), and other writings initiated by the classroom teacher. Activity sheets contained student written responses to inquiry-scaffolding questions (i.e. Break your Driving Question down into smaller parts.), specific notes (title, URL, main ideas) about resources encountered, comments about the trustworthiness of a site, and other question prompts related to studentsí inquiry. On-line postings included studentsí Driving Questions and subquestions, comments and questions to the teacher or peers, and critiques of sites utilized during the on-line unit. Artifacts were collected from each student pair for all MYDL units. In total, these included 1196 pages of activity sheets, on-line postings, final projects, and a number of other writings (e.g. journal entries, content summaries, process reflections) These artifacts (along with student interviews) provided a basis for the analysis of emerging content understandings of student pairs.

Semi-structured Interviews

A number of semi-structured interviews were conducted with student pairs during the study. These short (20 minute) interviews occurred approximately 1 week following the end of each on-line unit to assess the accuracy and depth of science content understandings. Interviews consisted of two parts -- the first segment assessed student understanding of Driving Questions held before the start of the inquiry unit (i.e. What did you know about your question before you started your unit? Where did you learn about that?), the second segment probed understandings gained as a result of student inquiry with on-line resources (i.e. Pretend Iím a reporter and want to find out about black holes. What can you tell me about them?). Specific questions were posed to observe if student understanding was limited to simple recall, or could be explained, articulated, or extended (What do you mean when you say a star is a middle star? How would that affect us on earth?) In total, this study produced 32 student interviews. This data (along with student artifacts) lends particular support to the content understanding research sub-questions.

Classroom-lab Video

The teacherís pedagogical influence on students were critical to characterize during this study. Classroom video was recorded for pre-lab, in-lab, and post-lab discussions and instruction-given by the teacher. These videos occurred in the regular or computer classroom (lab) and captured both the teacherís voice and student responses. This study collected 99 classroom videos ranging from 30 to 45 minutes each. The classroom video provided a perspective on the type of background, support, and instruction the teacher provided to students -- and how they responded to these scaffolds. It is understood that the pedagogical influence of the teacher may have a substantial effect on student development of content understandings. Given this potential, classroom video has the potential to inform each research sub-questions.

Summary

The breadth and variety of these sources provided an opportunity for a fine-grain of analysis. Many of the data collection techniques have been shown effective in early studies -- Process Video provides a reliable method in capturing student conversations and activity on-line, and student interviews are critical in assessing emerging understandings that may be hidden in artifacts.

The methodology described in this section are appropriate to answer the questions raised by this study. The techniques presented not only generated a rich collection of data, but more importantly furnished an extended view of student performance over the course of the entire school year -- a perspective previous studies did not provide. The year-long nature of this data will allow a high degree of insight into the research question: What is the nature of learnersí science content understandings as a result of utilizing on-line resources?

Data Analysis

The focus of this study is to provide insight into the depth and accuracy of learnersí science content understandings that emerged as a result of utilizing on-line resources. This section describes the coding and analysis techniques employed to develop responses to the research question.

Validity

The breadth of data sources utilized during this study permitted an analysis of the research question from a number of perspectives. Analysis was performed by triangulating these data sources to reduce any biases or limitations of specific methods. It is intended that this triangulation will reinforce the validity of conclusions drawn from this study and provide far more insight than previous studies (Hoffman, 1997; Hoffman, Kupperman, & Wallace, 1997; Lyons, Hoffman, Krajcik, & Soloway, 1997; Wallace, 1997; Wallace & Kupperman, 1997) that utilized limited data sources. In addition, the use of eight pairs of students and two teachers complemented by year-long data collection will enhance the validity of this study -- again, previous research used a limited number of participants for short term studies. Other aspects of the studyís methodology contributed to enhancing validity: Recording and transcribing interviews (instead of writing notes), and recording Process Video of studentsí work on-line (in place of detailed field observations). This combined methodology increased the likelihood of generating a valid description of the study, and reduced the possibility of inaccurate or incomplete data.

Analysis Stage Overview

Using the discussion of validity as a foundation, this section presents the stages of analysis utilized to explore the specific research question and sub-questions posed in this study. Three stages of analysis were conducted on the data collected during this study: 1) Data synthesis of Process Video, student interview audio tapes, and artifacts to assess content understandings, 2) Evaluation of depth and accuracy of content understandings, 3) Data synthesis and evaluation of classroom-lab video to assess possible pedagogical influences.

Stage 1: Content Understanding Data Synthesis

A large amount of data (student interviews, artifacts, Process Video) were collected during the study to provide insight into the depth and accuracy of content understandings gained from information-seeking activities. The first stage of analysis involved reducing this data using various coding schemes and analysis techniques. It was intended these analyses would provide the bulk of empirical support required to make claims regarding studentsí emerging content understandings.

Student Interviews

Student semi-structured interviews conducted at the conclusion of each content unit provided a fine-grained perspective on the understandings developed as a result of information-seeking. Interview data was transcribed and using a perspective of content understanding as described by Perkins, Crismond, Simmons, & Unger (1995). Given this conceptualization as a basis, major categories for coding depths of understandings, are illustrated by the following:

> 1. Recalling Information. This depth of understanding involves simply stating, repeating, or regurgitating facts from an information source. It is voiced with little or no interpretation from the learner, and is often stated in sparse segmented phrases or sentences. For example, "The moon is a lifeless satellite that orbits the earth."
>
> 2. Offering Explanations. This depth of understanding involves telling, describing with examples, pointing out critical features, and responding to new situations. It is often voiced in the form of complete thoughts possessing a high degree of coherence and meaning. For example, "The moon is a lifeless satellite because it does not have an atmosphere, and living things need an atmosphere to live."
>
> 3. Articulating Relationships. This depth of understanding involves expressing ideas with rich explanations, relating or linking concepts together, and illustrating with examples. It is often voiced in the form of multiple sentences that possess a high degree of coherence and meaning. For example, "The moon is similar to other smaller satellites that do not possess adequate gravity to hold in an atmosphere. The larger a satellite is, the more gravity it possesses and the more likely it is to contain an atmosphere."
>
> 4. Extending Explanations. This depth of understanding involves expanding concepts to new situations or circumstances, revising information, providing new examples, or going far beyond the original source of information. It is often voiced in the form of multiple sentences constructed with a high degree of thoughtfulness and meaning. For example, "If the earth had less gravity, there might be a good chance that earth would not contain the type of atmosphere it has today. Our planet might be more like the moon without an atmosphere, water, oxygen, or life."

In addition to these major categories, further coding divided content understandings into distinct areas of knowledge. These areas (interpreted from Bloom, 1974) include understandings related to:

> 1. Specific facts and isolated bits of information. For example, "The moonís period of revolution is 27.3 days."
>
> 2. Processes, directions, and movements of phenomena with respect to time. For example, "The moon moves through a series of phases each month -- new moon, waxing crescent, first quarter, waxing gibbous, full moon, waning gibbous, waning crescent, and back to new moon."
>
> 3. Methods, techniques, procedures utilized to support discovery and inquiry. For example, "The moonís period of revolution was observed by the ancient Chinese who used the information to develop a lunar calendar."
>
> 4. Theories, patterns, principles, and generalizations. For example, "Satellites, like the moon, obey Keplerís three laws of planetary motion, and are locked in orbit due to their gravitational attraction to a larger object.

A summary of the coding scheme, shown in Table 2, presents each of the four levels of content understanding, a description of each of the sub-categories for analysis, and the associated coding scheme.

Table 2

Coding for Depth of Content Understanding

Level	Code	Description
Recalling Information (stating, repeating)	RF	Recall specific facts and isolated bits of information.
	RP	Recall processes, directions, and movements of phenomena with respect to time.
	RM	Recall methods, techniques, procedures utilized to support discovery and inquiry.
	RT	Recall theories, patterns, principles, and generalizations.
Offering Explanations (telling, describing)	EF	Explain facts, information, and concepts.
	EP	Explain processes, directions, and movements of phenomena with respect to time.
	EM	Explain methods, techniques, procedures utilized to support discovery and inquiry.
	ET	Explain theories, patterns, principles, and generalizations.
Articulating Relationships (expressing, relating)	AF	Articulate facts and concepts.
	AP	Articulate processes, directions, and movements of phenomena with respect to time.
	AM	Articulate methods, techniques, procedures utilized to support discovery and inquiry.
	AT	Articulate theories, patterns, principles, and generalizations.
Extending Explanations (expand, revise)	XF	Extend facts and concepts.
	XP	Extend processes, directions, and movements of phenomena with respect to time.
	XM	Extend methods, techniques, procedures utilized to support discovery and inquiry.
	XT	Extend theories, patterns, principles, and generalizations.

Artifacts and Process Video

Student artifacts constructed at the conclusion of each inquiry unit also provided a fine-grained perspective on the understandings developed as a result of information-seeking activities. The physical appearance of these artifacts were described, printed text and presentation dialogue transcribed, and coded using the scheme developed for student interviews. In addition to final artifacts, in-process artifacts (MYDL activity sheets, on-line postings, journal writings) provided additional support for gaining insight on the sense-making process.

Process Video collected during each content unit provided additional views into how students constructed understandings using on-line resources. Although this data contained a wealth of information on how students used technological tools and engaged with information-seeking activities, specific episodes related to content synthesis were coded with a scheme similar to student interviews.

Data Synthesis

The data sources and coding schemes provided the opportunity to explore each research subquestion in detail to draw out the nature of learnersí content understandings:

> 1. What depth of content understanding (recalling information, offering explanations, articulating relationships, extending explanations) do learners possess and communicate as a result of utilizing on-line resources? To what extent are these made visible in learnersí products and conversations? These questions were explored through the analysis of artifacts (final products), student interviews, and Process Video over the course of the content units. Final products allowed a perspective of polished forms of student content understandings and interviews (conducted a week or more after the creation of the final product) provided insight into learnersí short-term retention of concepts. Also, Process Video allowed a view of how students constructed understandings while on-line.
>
> 2. How accurate are the content understanding (inaccurate, none, partial, accurate) that learners possess and communicate as a result of utilizing on-line resources? To what extent are these made visible in learnersí products and conversations? These questions were explored through similar analyses of data sources as described above.

Additional analyses were performed to create a representation of student content understanding present after engaging in information-seeking activities. Figure 9 shows the depth and accuracy of understandings learnersí developed and retained as a result of their inquiry.

Figure 9. Understandings for "How do black holes form?" by Angela-Jamie (pair 3)

Accuracy of Understanding																
Accurate	x	x			x	x				x			x			
Partial							x		x					x		
None			x	x				x			x	x			x	x
Inaccurate																
	RF	RP	RM	RT	EF	EP	EM	ET	AF	AP	AM	AT	XF	XP	XM	XT
	Recalling Information				Offering Explanations				Articulating Relationships				Extending Explanations			
	Depth of Understanding															

Stage 2: Content Understanding Evaluation

The second stage of analysis involved evaluating learnerís content understandings for each content unit. The purpose of this stage was gain broad insights into learnersí depth and accuracy of content understandings as a result of their year-long information-seeking activities.

To facilitate this effort, further data analysis was performed on the initial coding and analysis of student understanding shown previously in Figure 9. Divisions for depth of understanding (specific facts, processes, methods, theories) were consolidated into a single data point for each category (recall, explain, articulate, extend) to provide a graphical summary (Figure 10). Determination of these summary points were based on the presence of any division of understanding in the category and the highest accuracy of understanding. However, incorrect understandings were also included in the graph along with partial or accurate understandings. This represents a student possessing an accurate depth of understanding for a single concept in a topic, but at the same time holding possible incorrect conceptions.

Figure 10. Content Understanding Summary for Angela-Jamie (pair 3):

Accuracy of Understanding									
Accurate	x	x			Accurate	x	x	x	x
Partial					Partial				
None			x	x	None				
Inaccurate					Inaccurate		x		
	Recall	Explain	Articulate	Extend		Recall	Explain	Articulate	Extend
	Depth of Understanding **Unit 1 - Weather**					**Depth of Understanding** **Unit 2 - Astronomy**			

Accurate	x	x			Accurate	x	x		
Partial					Partial			x	
None			x	x	None				x
Inaccurate					Inaccurate				
	Recall	Explain	Articulate	Extend		Recall	Explain	Articulate	Extend
	Depth of Understanding **Unit 3 - Geology**					**Depth of Understanding** **Unit 4 - Ecology**			

Further analysis involved developing broad statistics to illustrate the number of units where students achieved various depths of content understandings (recall, explain, articulate, extend). In addition, these were separated by teacher to gain insight into possible pedagogical influences. Table 3 shows an example of the highest depth of understanding obtained by students for the four inquiry units completed during the study.

Table 3

Highest Depth of Understanding (with accuracy) Achieved for Nanciís Students

	Unit			
Student Pair	1	2	3	4
5) Britt - Tanya	RI	RI	RI	AR
6) Kurt - Mike	RI	RI	RI	RI
7) Grant - Robert	RI	RI	RI	RI
8) Brooke - Karley	RI	RI	RI	OE

Note: RI = recalling information, OE = offering explanations, AR = articulating relationships,

EE = extending explanations. 88% of units resulted in a highest level of understanding at recalling information, 6% at offering explanations, 6% at articulating relationships, and 0% at extending explanations.

Additional analyses were conducted to determine studentsí accuracy of understandings for the accurate, partial, and incorrect levels. For example, Table 4 shows where incorrect understandings occurred in conjunction with, or in place of, partial or accurate understandings. Again, these were separated by teacher to gain insight into possible pedagogical influences.

Table 4

Units Containing Incorrect Understandings for Nanciís Students

	Unit			
Student Pair	1	2	3	4
5) Britt - Tanya	I	I	I	
6) Kurt - Mike				
7) Grant - Robert		I	I	
8) Brooke - Karley	I		I	

Note: I = incorrect understanding. 44% of units contained incorrect understandings resulting from the use of on-line resources.

These analyses provided the bulk of empirical evidence to make claims regarding studentsí depth and accuracy of understanding constructed over the length of the study. Further insight on possible factors that influenced these constructions were evaluated in the following stage.

Stage 3: Classroom-Lab Data Synthesis and Evaluation

Classroom-lab video data collected during the length of the study provided a perspective on how teacher pedagogy may have influenced the degree to which students engaged in information-seeking activities. This data was viewed, transcribed, and coded in a number of broad categories including:

1. Classroom Discussion (General). The teacher leads, moderates, or participates in a discussion about a general classroom topic (not related to the investigation). For example: Having a conversation about an mathematics assignment that is due the next day.

2. Classroom Discussion (General Investigation). The teacher leads, moderates, or participates in a discussion about a general topic related to the inquiry unit. For example: Reviewing parts of the Investigation Wheel with students.

3. Classroom Management. The teacher attempts to manage the behavior and activities of the whole classroom or an individual student. For example, "This class is being much to loud... you need to quiet down so we wonít disturb other students in the Media Center."

4. Question Response. The teacher responding to a specific question from a student. For example, "Yes, that is correct, there are no black holes in our solar system."

5. Review Content. The teacher reviews science content or information learned during a lesson with students. This is accomplished through question-answer or discussion with students. For example, "Sue, tell the class what you learned about hurricanes today."

6. Strategy Instruction. The teacher provides scaffolded instruction to students in an effort to develop or enhance inquiry strategies (related to ask, plan, search, assess, synthesize, write, create). This instruction may be visible in the form of presenting or discussing MYDL activity sheets, modeling, reviewing, summarizing, making suggestions, etc. For example, "Letís take a look at this Driving Question... as you can see, it is very closed-ended. Finding how many tornadoes occurred in Michigan is a one word answer. Jamie, tell us how to make it into a good Driving Question."

7. Student Monitoring. The teacher monitors the progress of students by physically moving to their location and providing assistance, or asking questions to the entire class and eliciting a response. For example, "I can see we are having a difficult time connecting to the server today, letís all click the stop button and have just one student try it."

8. Task Instruction. The teacher provides explicit instructions to students about their immediate task. For example, "I would like all of you to get out your journals and find a clean page to write on."

Table 5 presents a summary of this coding scheme with the event, description, and code for the activities occurring in Heatherís and Nanciís classrooms and labs.

Table 5

Coding Categories for Classroom-Lab Video

Event	Code	Sub-Code	Description
Classroom Discussion (General)	CDG		Leading, moderating, or participating in a discussion unrelated to the investigation.
Classroom Discussion (General Investigation)	CDI		Leading, moderating, or participating in a general discussion related to the investigation.
Classroom Management	CM		Attempts to manage the behavior or activities of students.
Question Response	QR		Responding to a question from a student or group.
Review Content	RC		Review science content with students through question-answer or discussion.
Strategy Instruction	SI		Scaffolded instruction to develop or enhance studentsí inquiry strategies.
	SI	Q	Related to asking questions.
	SI	P	Related to planning.
	SI	S	Related to searching.
	SI	A	Related to assessing
	SI	Z	Related to synthesizing
	SI	W	Related to writing.
	SI	C	Related to creating.
Student Monitoring	SM		Monitoring and supporting students by providing individual help and suggestions.
Task Instruction	TI		Providing explicit instructions to students regarding an immediate task.

In addition to this coding, general notes (observer comments) were made during the viewing of classroom and lab video to capture how students responded to the teacherís scaffolding, directions, and questions.

The result of this data synthesis was used to evaluate the general pedagogical practices of teachers to determine if they influenced the degree to which learners constructed broad and accurate content understandings. This comparison was accomplished through an analysis of coded Classroom-lab video with specific attention paid toward the scaffolds teachers provided to assist with synthesizing information found on-line. Summary tables were created to show the similarities or differences between teacher supports.

This section described the methodology utilized for this research and various coding schemes used to organize data to gain insight into the research question and subquestions. The range of analysis and breadth of data sources provided an opportunity to gain a substantial amount of insight into the nature of learnersí content understandings. This analysis also illustrates the use of data triangulation to gain the greatest possible validity for this study -- it is intended this triangulation will reduce any biases or limitations from specific methods. In addition, triangulation will reinforce conclusions drawn from this study and provide a greater depth of insight compared to previous MYDL studies that utilized limited data sources.

Results

The purpose of this research was to gain insight on the impact of utilizing the World Wide Web as a technological tool to enhance content understandings in secondary science classrooms. More specifically, the study focused on a central question: What is the nature of learnersí science content understandings as a result of utilizing on-line resources? Two sub-questions relating to this central questions were analyzed using data sources (Process Video, student artifacts, student semi-interviews, classroom-lab video) combined with a variety of coding and analysis techniques. The methodology for gaining insight into the research questions and sub-questions involved three distinct stages: 1) Data synthesis of Process Video, student interview audio tapes, and final project artifacts to assess content understandings, 2) Evaluation of depth and accuracy of content understandings, 3) Data synthesis and evaluation of classroom-lab video to assess possible pedagogical influences.

Data collected from eight sixth-grade student pairs during four Middle Years Digital Library content units provided the basis for making claims relative to the nature of learnersí content understandings. Of importance were the depth (recalling information, offering explanations, articulating relationships, extending explanations) and accuracy of content understandings. The analysis of this data resulted in the following findings:

1. The majority of learners constructed understandings limited to recalling information or offering explanations, and only few demonstrated the ability to expand understandings to articulate and extend levels.

2. The majority of understandings occurred at the partial level. Students more frequently developed limited understandings of concepts and had difficulty obtaining accurate conceptualizations.

3. A number of students developed (or held to) inaccurate understandings, with the majority of these occurring in Nancyís classes.

4. Clear differences in teachersí pedagogical practices were apparent during the study, with Heather providing more extensive scaffolding. These efforts translated into learners who developed more accurate content understandings (no substantial patterns emerged for depth of understandings).

This section presents the detailed results of this study. Accompanying these results are evidence drawn from artifacts, student interviews, and Process Video to support

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conclusions.

Content Understandings: Depth

Students constructed meaningful understandings as a result of their investigations but were often limited to recalling information or offering simple explanations. Although student artifacts were represented with factual content, their conversations revealed a much deeper level of understanding. No substantial difference in the depth of understanding was noted between participating teachers.

This study assessed the depth of understandings learners constructed as a result of information-seeking activities with on-line resources, and how they were communicated in final products and conversations. Data from student interviews, artifacts, and Process Video were analyzed and coded into four categories (recalling information, offering explanations, articulating relationships, and extending explanations) using techniques described in the methodology section. Table 6 shows a summary of the highest depth of content understandings Heatherís and Nancińs students developed (with partial accuracy) for the four content units they engaged in during the school year. Table 7 displays a similar summary for understandings developed at the highest level of accuracy.

Table 6

Highest Depth of Content Understanding (partial accuracy)

	Unit			
Student Pair	1	2	3	4
Heatherís Students				
1) Brett - Cedric	RI	RI	OE	OE
2) Edward - Kevin	RI	EE	OE	AR
3) Angela - Jamie	OE	EE	OE	AR
4) Brad - Gabe	RI	EE	EE	OE
Nancís Students				
5) Britt - Tanya	OE	EE	OE	AR
6) Kurt - Mike	OE	OE	OE	AR
7) Grant - Robert	OE	OE	AR	AR
8) Brooke - Karley	AR	OE	OE	OE

Note: RI = recalling information, OE = offering explanations, AR = articulating relationships, EE = extending explanations. Partial accuracy was defined as a response that is for the most part correct, but contains some element of incorrect information or a hesitancy to respond.

Table 7

Highest Depth of Content Understanding (highest accuracy)

	Unit			
Student Pair	1	2	3	4
Heatherís Students				
1) Brett - Cedric			RI	RI
2) Edward - Kevin	RI	AR	OE	AR
3) Angela - Jamie	OE	EE	OE	OE
4) Brad - Gabe	RI	EE		OE
Nancifs Students				
5) Britt - Tanya	RI		RI	AR
6) Kurt - Mike	RI	RI		
7) Grant - Robert				
8) Brooke - Karley			RI	OE

Note: RI = recalling information, OE = offering explanations, AR = articulating relationships, EE = extending explanations. Accurate was defined as a response absent of incorrect or erroneous information. Blank entries indicate students demonstrated partial accuracy only.

This analysis underwent further refinement and a summary table constructed (Table 8) to show the percentage of Heatherís and Nancifs units where students were able to obtain accurate and partial levels of understanding during the four content units. Based on this analysis, a number of units had resulting understandings limited to recalling information (35%) or offering explanations (32%), and only a few demonstrated the ability to expand conceptualizations to articulate (22%) and extend (12%) levels. It is interesting to note that some units (38%) did not produce content understandings beyond partial accuracy. In a comparison of Heatherís and Nancifs classes, no substantial patterns (for depth of understanding) emerged other than a tendency of Nancifs students to articulate concepts more (16% compared to 6%), and Heatherís students to extend concepts more (9% compared to 3%).

Table 7

Summary of Highest Depth of Content Understanding

	Number of Units				
	Heatherís Students		Nancifs Students		
Depth	Accurate	Partial Only	Accurate	Partial Only	Description
Recall Information	4	2	5	0	Simply stating, repeating, or regurgitating facts from an information source. Voiced with little or no interpretation from the learner, and is often stated in sparse segmented phrases.
Offer Explanations	5	0	1	4	Telling, describing with examples, pointing out critical features, and responding to new situations. Voiced with complete thoughts possessing a high degree of coherence.
Articulate Relationships	2	0	1	4	Expressing ideas with rich explanations, relating or linking concepts together, and illustrating with examples. Voiced with multiple sentences that possess a high degree of coherence.
Extend Explanations	2	1	0	1	Expanding concepts to new situations or circumstances, revising information, providing new examples, or going far beyond the original source of information.

Note: Values indicate the number of units (32 total) where students demonstrated understandings at accurate and partial accuracy. Accurate was defined as a response absent of incorrect or erroneous information. Partial was defined as a response that is for the most part correct, but contains some element of incorrect information or a hesitancy to respond.

Given this analysis, the majority of students appeared to construct understandings limited to a basic recall of information or simple explanation. Evidence from student interviews illustrate the limits of typical learners.

Brett and Cedric (pair 1) - Weather Investigation (unit 1)

Interviewer:	Cedric, what would be another important thing (about sprites)?
Cedric:	Like they come in different forms.
Interviewer:	How do you mean different forms?
Cedric:	Like fireworks or like two people dancing, umm, oh yeah, or red sprites and blue jets.
Interviewer:	I need one more thing.

Brett:	Probably like their colors. Cause, they have colors white, red, blue and it was pretty cool because of them had like blue jets and they would turn into a sprite and a sprite would be red and eventually turn into a sprite that was white.
Interviewer:	It sounds like you know a lot about what sprites look like. Did you find out about anything that causes them?
Brett:	It was upper atmosphere electricity, I think, like from lightning.
Interviewer:	Do sprites only happen at the top of clouds? Do they ever happen at the bottom of some clouds?
Brett:	They don't really happen at clouds, it is from the electricity in the air. It just gives off a flash and its umm... they don't really form in the air they just umm... they form in the air not near clouds so it's pretty much anywhere.

This interview demonstrates how students were confined to a simple restatement of facts (with sparse phrases) and could not provide additional explanation to specific questions. Students could not explain how sprites are associated with thunderstorms clouds and can only be recorded with special cameras utilizing low light level technology. Also, students assumed sprites occurred anywhere in the sky when research has shown they only occur at the top of clouds. Other interviews provide similar insights to the limits of student understanding:

Edward and Kevin (pair 2) - Weather Investigation (unit 1)

Interviewer:	What did you find out (about hurricanes)?
Edward:	We found out that it needs sea water above 80 or 90 degrees and that it is high pressure above the low pressure above the water and converging winds. That creates a hurricane and they go up like that.
Interviewer:	So they go up...
Edward:	It becomes like a cycle. They go up and it comes back down and it goes over and over again and it turns into a hurricane.
Interviewer:	Kevin, anything to add to that? What did you learn about hurricanes?
Kevin:	No, not much. Umm... (long pause)

Although these students have some element of explanation in their responses, they have considerable difficulty moving beyond recalling discreet information. They were not able to explain that hurricanes require three conditions to form (and to strengthen): Warm surface waters, high humidity, and the ability to concentrate heat vertically. This simple level of recall was typical of the many learners participating in the study.

However, some learners developed rich understandings as a result of their efforts on-line and could both articulate and extend their explanations. Evidence from student interviews illustrate this depth of understanding:

Angela and Jamie (pair 3) - Astronomy Investigation (unit 2)

Interviewer:	Jamie, tell me what you learned about black holes.
Jamie:	I learned that the black hole itself, the reason it is black and you can't see it is because it sucks in light and light cannot escape so you wouldn't see it and x-rays do detect them, but you don't see how big, you just see like the gravitational pulls and you can't see the particles... and like when they find one they know, they can track down how much gravitational pull it has but they don't know how wide it is and they really don't know what size.
Interviewer:	Why does it pull things into it?
Jamie:	I know. The reason it pulls it in is because when the star, like when the super nova occurs it blows up and like the dust particles and stuff get like pulled together because of space and then after that they just sort of suck everything in because they are use to having a gravitational pull in a certain direction so it continues to do it and it sort of makes like a funnel kind of shape... and everything sort of is just draining in it.
Interviewer:	Anything else you learned about black holes?
Jamie:	Well ahh, I wouldn't want to be sucked in one. It'd be like a painless way of committing suicide though because you'd only be alive for like a second.
Interviewer:	Why would that be?
Jamie:	Well, because it stretches you, it stretches you so much that you'd just be a strand of spaghetti and so because it's stretching you just collapse in on yourself.

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Interviewer:	Which would be a bad thing.
Jamie:	Yeah. (laughter)

This interview segment illustrates how some learners could reach beyond merely recalling information and express ideas with relating and linking concepts together, expanding concepts to new situations, and going beyond the original source of information. Other examples of this rich content knowledge was gathered through student interviews:

Britt and Tanya (pair 5) - Geology Investigation (unit 4)

Interviewer:	Can you tell me anything more about how to prepare for an earthquake? Youfve all ready talked about a lot of things.
Tanya:	We found that things that are likely to break, that you shouldn't be near them. This shelf has glass and stuff on it, you don't want to stand by it. If you're by your china table or whatever, you don't want to be like, "oh, no, not my china" and then be standing by it holding it up and then it falls and break on you, everything's going to break and when you try to get pass it your going to cut yourself and get cuts and stuff.
Interviewer:	Anything else about preparing for an earthquake?
Tanya:	There's a lot of stuff to do. Umm, they said like for, like over there if you have a leaky ceiling or if your ceiling are cracking or the walls have little cracks in them, you should immediately replaster them and like if there's anything wrong with your floors or like, what my parents said is like if you have things that are likely to move, like these tables or these chairs or something, for sofas what you should get and like tables, you should get those stoppers that you put under them so that they don't slide around. They are kind of like rubber so that they don't move around. If you have an earthquake or a tornado or something then instead of having all the furniture moving around it just stays.
Britt:	Can I say something about the tornado? The furniture doesn't move it just goes phew (motions horizontally with hand)!

An interesting observation made during the analysis of data was the stark difference between the depth of understanding apparent in student artifacts (including presentations) and those articulated during student interviews. A review of final products and presentations revealed little about the true depth of learnersí content understandings -- these artifacts often communicated a simple recall of factual information. Student interviews permitted a fine-grained view of these understandings, and concepts were probed to determine true depths of conceptualizations. This was true for all levels of student pairs, including those with the weakest understandings. The following example illustrates the contrast between artifact and interview:

> Karley and Brooke (pair 8) have created a simple poster for their weather investigation (What is El Nino?). One section reads: "What is El Nino? El Nino is a disruption of the ocean's atmosphere. In other terms it is when the ocean water changes it temperature, sometimes it changes by 1 degree, 2 degrees, and even up to 5 degrees. This change really affects the weather sometimes in good ways and other times in bad ways. El Nino can cause severe tornadoes, hurricanes, floods, etc. In good ways it can make your winters milder and nicer and springs seem earlier."

Karley and Brooke (pair 8) - Weather Investigation (unit 2)

Interviewer:	I noticed this winter we had a lot of warm days and we really didn't have as much rain or snow as we did normally. Why was that, if you said El Nino effected us? What caused us not to have as cold or as rainy?
Karley:	I think because like the cold weather we usually have was up more towards like Canada and the Upper Peninsula and we got what Tennessee and Kentucky usually have for their winters and that's usually just a little snow and warm days and stuff like that.
Interviewer:	Oh, I see. So what you're saying is it just kind of pushed all the weather up. Do you think we are going to have to worry about this next year?
Karley:	Probably not. Probably the ocean temperature won't change like it did this year. It will just stay at normal temperature.
Brooke:	Yeah, it will probably just stay. It will probably go back to its normal temperature. It won't change.

Although the artifact lists only general facts related to the change in weather patterns, students were able to offer additional explanations during the interview to illustrate a deeper understanding of weather phenomena.

This study assessed the depth of content understandings learners possessed and communicated as a result of their activities on-line. Students demonstrated their ability to construct meaningful understandings, but these were often limited to recalling information or offering simple explanations. In addition, interviews proved to be a source of learnersí true depth of understanding as artifacts contained only factual information.

Content Understandings: Accuracy

Some students developed accurate content understandings from their work with on-line resources. However, a substantial number experienced difficulty constructing accurate understandings, and as a result constructed conceptualizations that were only partially accurate. A number of learners developed (or held to) inaccurate understandings. A difference was noted in studentsí accuracy levels between participating teachers.

In addition to obtaining a view into studentsí depth of content understandings, this study assessed the accuracy of understanding learners possessed and communicated as a result of using on-line resources. Data from student interviews, artifacts, and Process Video were analyzed and coded into four categories (accurate, partial, none, inaccurate) using techniques described in the methodology section. Table 9 shows a summary of the results from this analysis for the four inquiry units corresponding to Heatherís and Nancís students

Table 9

Summary of Unit Accuracy

	Unit			
Student Pair	1	2	3	4
Heatherís Students				
1) Brett - Cedric	p	p i	a p	a p
2) Edward - Kevin	a	a p	a p	a
3) Angela - Jamie	a p	a i	a	a p
4) Brad - Gabe	a p	a	p	a p
Nancís Students				
5) Britt - Tanya	a p i	a p i	a p i	a
6) Kurt - Mike	a p	a p	p	p
7) Grant - Robert	p	p i	p i	p
8) Brooke - Karley	p i	p	a p i	a

Note: a = accurate, p = partial, i = incorrect understandings. Values for content understandings indicate any occurrence of accurate, partial, and incorrect understandings in each content unit and the transfer task.

The results from this analysis were utilized to create a summary to illustrate the highest accuracy of understanding obtained during the inquiry units. Table 10 shows the accurate, partial, and inaccurate levels of understanding for the units completed in both Heatherís and Nanciís classes. Based on this analysis, it appears most understandings occurred at the partial level (44%), followed by the accurate level (39%). This implies students more frequently developed limited understandings of concepts and had difficulty obtaining accurate conceptualizations. An interesting insight is the presence of a larger percentage of accurate understandings in Heatherís students (24% compared to 15%) and a higher frequency of inaccurate understandings (13% compared to 4%) in Nanciís students.

Table 10

<u>Summary of Content Understanding Accuracy Levels</u>

	Percentage of Coded Understandings		
Accuracy Level	Heatherís Students	Nanciís Students	Description
Accurate	24	15	Demonstrated by an accurate response that is absent of incorrect or erroneous information.
Partial	20	24	Demonstrated by a response that is for the most part correct, but contains some element of incorrect information or a hesitancy to respond.
Inaccurate	4	13	Demonstrated by an response that is considered incorrect or not accepted as factual in scientific terms.

Note: Values indicate the percentage of understanding accuracy that were coded (54 total) for the 32 units students completed.

Given this analysis, the majority of understandings learners constructed were at partial levels of accuracy with Heatherís students demonstrating more accurate conceptualizations than Nanciís. In addition, Nanciís students had a high incidence of incorrect understandings. These may have resulted from an incorrect construction of understandings, or evidence of previously held conceptions. Data from student interviews lend insight into these understandings:

<u>Grant and Robert (pair 7) - Astronomy Investigation (unit 3)</u>

Interviewer:	Okay, you mentioned that they (asteroids, comets, meteors) moved at different speeds. Why would they move at different speeds? What did you learn about that?
Robert:	The amount of energy they have inside of them the nucleus, umm, sometimes if they have very much and they're like really old asteroids or comets then they move really slowly and if they're maybe a newer one, then they go faster.
Interviewer:	Where would they get that energy inside? Where did it come from?
Robert:	Umm, I think it would come from, I just don't know like some of the oldest how they came to be, you know, comets, so they just knew the energy there but they don't know where it came from or maybe cause they were inside a planet that had energy inside of it. Maybe it exploded so the pieces of rock had energy inside of it.

This dialogue indicates students have an incorrect understanding of both the origin and mechanisms of motion for asteroids, comets, and meteors. They failed to learn all astronomical objects (planets, asteroids, comets, etc.) that reside in or periodically visit our solar system are in constant motion around our sun due to gravitational forces between bodies (i.e. sun and earth, sun and comet). Since there is no friction to disrupt the motion of objects in space, bodies stay in continuous motion. Although students spent seven sessions researching this topic (What makes comets, asteroids, and meteors move?), they were unable to construct an accurate (or partially accurate) response to their Driving Question. The root of their alternate conception may originate from a connection made from topics learned previously in science class. When asked about the source of information on comet motion, Robert replied:

> "Umm, they (the Web) don't have a lot of information about it but we found out about the energy in science and it didn't exactly say that the energy makes the comet move but we just like after planning together what it says and all the things we read that the energy does make it move but it's also the thing that they're orbiting around."

Although Robert had some knowledge of gravitational influences, he admits the "energy inside" has a "bigger effect" on motion. A review of studentsí final artifact (newspaper article) shows similar incorrect conceptions:

> "Exciting news from NASA today. Two comets that are traveling fast are on track to collide in 5 days at 9:30 pm. If you are outside watching you will be able to see it. Scientists believe you will see bright sparks of blue. Then there will be a bright flash of red then nothing. The energy in the middle of the (sic) is supposed to mix gases together and make another comet but nobody in (sic) sure. Comets, like meteors and asteroids are powered by the energy within them."

Other examples of understandings are evident in an interview conducted with Brooke and Karley (pair 8) after the ecology investigation (What most deadly disease is found in water?). When asked if people should stay away from untreated water, Karley replied:

> "They should try not to drink but if they get a little bit it probably won't hurt them that much."

Also, when asked how people get coliform bacteria, Karley commented

> The coliform bacteria came in rusty pipes and like the other one came from not washing your hands and like eating things that have been like a bug got to and stuff like that.

Students clearly have incorrect understandings about the origin and dangers of contaminants found in drinking water. These students have not yet developed a correct understanding that bacteria is very small and only microscopic quantities are necessary for the spread of disease. In addition, water contamination with fecal material from sewage systems is the primary cause of the occurrence of coliform bacteria, and not rusty pipes or the presence of insects. The origin of this alternate conception could not be traced to a source or associated ideas -- however, students mentioned they had no previous understanding on this topic and used only Web-based resources to answer their Driving Question.

This study assessed the level of accuracy learners possessed and communicated as a result of their activities on-line. Although many students developed accurate content understandings from their work with on-line resources, a substantial number constructed conceptualizations that were only partially accurate, and some formed (or held to) inaccurate understandings.

Pedagogical Practices:

A clear difference in pedagogical practices between participating teachers was observed during the study, with Heather providing more extensive scaffolding for information-seeking strategies. These differences in practices and scaffolds did not appear to influence learnerís depth of content understandings, but may have impacted studentsí accuracy of understanding.

The extent that participating teachers scaffolded the development of information-seeking strategies (inquiry strategies) with students may have impacted studentsí accuracy of understanding. As presented previously (Table 9), a larger percentage of accurate understandings occurred with Heatherís students (24%) compared to Nanciís (15%). Also, Heatherís students had less occurrences of inaccurate understandings (4% compared to 13%). Throughout the school year, Heather had a strong focus on the development of good Driving Questions, utilization of tools to support inquiry, and use of on and off-line resources for synthesis. In addition, she stressed the ongoing improvement of inquiry strategies and process skills to students, and encouraged them to use their Wonder Books (a journal exclusively used for science investigations) as a medium for reflection and synthesis of content. Nanci, in contrast, did not focus as strongly on process skills and did not demand the same level of participation from students. Table 11 summarizes the main pedagogical differences in scaffolding information-seeking strategies (questioning, planning, tool use, searching, assessing, synthesis, writing, creating) between Heather and Nanci.

Table 11

Comparison of Inquiry Strategy Pedagogical Practices of Teachers

Pedagogical Practice	Heather	Nanci
Questioning Strategies	Wonder Books used as the basis for question development. Specific lessons targeted attributes of good Driving Questions, with substantial rehearsing and review. Activities included extensive critique of peersí questions on-line. Attributes reviewed during the school year.	Questions often pulled from recent classroom science topics. Presentation of Driving Question characteristics with examples and student-teacher discussion. Student development of question attributes stressed. Some critique of peersí Driving Questions on-line.

Table 10 - continued

Comparison of Inquiry Strategy Pedagogical Practices of Teachers

Pedagogical Practice	Heather	Nanci

Planning Strategies	Collaborative development of grading rubrics. Encouraged students to list planning steps. Focused on daily reflection of progress and development of sub-goals. Many on-line sessions were highly-directed by the teacher.	Formal step-by-step plans required during investigations. Little reflection on individual progress at the end of each session. Large percentage of on-line sessions are specified by goals listed on the board before working in the lab.
Tool Use Strategies	Numerous discussions and explicit instructions on the use of Artemis. Public sharing of techniques encouraged between groups. Use of Artemis features were somewhat monitored and feedback provided.	Competency with tools assumed from Scavenger Hunt. Specific directions given on the use of basic Artemis features. Advanced featured provided individually to students but not to the group as a whole.
Searching Strategies	Specific activities provided to help with the development of search topics. Stressed locating many different sources of information on and off-line. Encouraged students to look deep into sites and read text for useful information.	Search topic ideas constructed as a class and provided to students. Individual search topic support provided only during on-line sessions. Encouraged students to read text for useful information.
Assessing Strategies	Specific examples and instruction provided to determine the usefulness and trustworthiness of sites. Stressed the use of viewing the URL (gov, org, com, edu) for assessing source quality.	Site comparison activity (MYDL activity sheet) used to illustrate comparing resources for trustworthiness. Utilized MYDL Assess activity to scaffold strategies. Provided hints on the use of URLs to determine source quality.
Synthesis Strategies	Discussion between partners and groups encouraged, making thoughts public important. Stress answer construction from many different sources. Little direct instruction on how to synthesize content using student discussion as a basis.	Conducted activities with concept maps to help with studentsí construction of understanding. Minor instruction on how to synthesize content through student discussion.
Writing Strategies	Required students to record detailed navigation steps, judge relevancy of information, and provide comment on content. Wonder Books utilized extensively as a journal for processing thoughts and information.	Required students to complete MYDL activity sheets during on-line sessions and used this task as a method for evaluating students. Additional reflection or content writing not stressed.
Creating Strategies	Some freedom given to students on product format. Whole class in-depth presentations for each unit included content and process. Teacher probed students for clarification on content during presentations. Question-asking by students encouraged.	Provided many options for final products, stressed a focus on content. Presentations tended to be very short with little feedback from the teacher or questions from students.

Although a direct relationship between the scaffolding of inquiry strategies and accuracy of content understandings is difficult to establish, Heather did attempt to engage students in a number of synthesis and writing activities that Nanci did not. These included: digging deep into sites to find pertinent content, utilizing multiple sources of information (including print-based materials), paraphrasing information before recording it on paper, using Wonder Books as a method of journaling thoughts and ideas, being selective about what was recorded on paper, and reflecting on notes (and progress) at the end of most sessions. Perhaps this scaffolding required students to process information more thoroughly which enhanced their accuracy of understanding.

In addition to the scaffolding of inquiry strategies, a comparison of general pedagogical practices provided additional insight into the classroom environment. Table 12 compares the pedagogical practices (classroom management, task instruction, student monitoring, classroom discussion, question response) of Heather and Nanci. This analysis showed how Heather provided more clear expectations for behavior in the classroom, gave more specific instructions and guidance, elicited feedback from students for the groupís benefit, and focused on scaffolding the group as a whole. Heatherís classroom could be characterized as more on-task, focused, directed, collaborative, and engaging than Nanciís. These differences translated into differences in the engagement with inquiry strategies (and resulting content understandings) of Heatherís and Nanciís students during the content units. Based on this analysis, it could be inferred the more teachers scaffolded studentsí development of inquiry strategies, the more accurate the resulting content understandings.

Table 11

Comparison of General Pedagogical Practices of Teachers

Pedagogical Practice	Heather	Nanci
Classroom Management	Students tend to be quiet and orderly while teacher talks, most misbehavior is not tolerated and swiftly corrected with consequences. Most work sessions are business-like and closely monitored.	Students tend to be quiet and orderly while teacher talks, some behavior is tolerated in special needs students. Many misbehaviors are verbally corrected. Work sessions are often noisy with some off-task behaviors.
Task Instruction	Students are given explicit verbal directions in small segments. Instructions are very specific and little opportunity is given for individual interpretation.	Students are given broad directions which are often listed on the chalk board. Instructions provide the opportunity for individual pacing and are open for interpretation.
Student Monitoring	Students are monitored as a large group with some individual support. Feedback and guidance are given to the group with a high level of interaction between the teacher, groups, and peers.	Students are closely monitored during on-line sessions. Feedback and guidance are given individually rather than in a large group.
Classroom Discussion	Although much discussion is from the teacher to students, there are many opportunities for inter-group discussion, sharing, and critiquing. Pausing for a discussion during on-line sessions is common.	The majority of discussion is from teacher to student, and student to teacher. Each student is often called upon to reply. Only some discussion is between groups.
Question Response	Responses to questions often involve students rethinking ideas. Questions are often posed to the entire group for a response.	Answers to questions are given to students directly, with some posed to the entire group.

However, both teachers had pedagogical practices that could have been improved upon to foster improved depth and accuracy of content understandings: 1) Although teachers expected groups to synthesize content in writing, they did not require them to frequently pause and engage in a healthy discussion about the information -- students often wrote notes directly from Web pages with little or no conversation. 2) Teachers did not provide a strong enough critique of learnersí in-process and final artifacts -- students often exerted minimum effort and received good grades for the project. 3) Teachers were not able to effectively support learnersí sense-making and help mediate the formation of understanding -- some students developed strong incorrect conceptions, or held on to previous understandings when constructing meaning from on-line resources.

This research focused on the ability of eight pairs of middle school students to engage in information-seeking activities in on-line environments. Of particular interest was the depth and accuracy of content understandings learnersí developed and how the pedagogical practices of teachers influenced their construction. A number of conclusions to questions posed at the beginning of this study were discussed in this section, and a discussion of these results are presented in the following section.

Discussion

The purpose of this study was to gain insight into the nature of learnersí content understanding as a result of their use of on-line resources. This study incorporated a methodology that included a number of participants, a variety of data sources collected over an entire school year, fine-grained methods for the coding of data, and three stages of analysis for obtaining responses to the research question and subquestions. In addition, this study offered extensive technological and pedagogical supports to provide a rich learning environment for students. These included: The University of Michiganís Digital Library (UMDL) - a comprehensive set of age and content appropriate digital resources, Artemis - a student interface to the UMDL, Middle Years Digital Library (MYDL) On-line Learning Materials - a contextual setting with sharing tools to support on-line inquiry, and Tactics and Strategies for Leading On-line Investigations - a set of print-based support materials to assist learners with the development of inquiry strategies, and a model for teachers to help instantiate on-line inquiry in the classroom. The learning environment was carefully constructed to provide both the framework and resources to support learners in their information-seeking activities on the World Wide Web.

A number of conclusions were drawn from this year-long study describing how students constructed content understandings from on-line resources. Although a number of learners could express understandings with explanations constructed from linked information (articulate), or revise and expand explanations beyond original sources of information (extend), the majority of students could only recall basic facts or offer simple explanations. An interesting observation from the data was the factual representation of understandings apparent in student artifacts -- learners rarely went beyond a simple presentation of facts, although their conversations (student semi-structured interviews) demonstrated a more broad depth of understanding.

In addition to learnersí depth of understanding, perspectives were gained on the accuracy of student learning. Many students demonstrated a high degree of accuracy in their understandings, but a substantial number experienced difficulty in their sense-making efforts and constructed conceptualizations that were only partially accurate. Perhaps the most surprising perspective gained from the analysis was the number of learners who developed or held to inaccurate understandings.

This study also found clear differences between student pairs, and these variations were attributed to the efforts of the participating teachers. While one teacher provided substantial scaffolding to assist students in developing strategies for asking questions, planning inquiry activities, using on-line tools, searching for resources, assessing sites, writing about information, and creating artifacts, the other teacher provided less support. This difference in support could be attributed to the higher occurrence of inaccurate understandings, but the data was not conclusive.

Given these conclusions, a number of questions, issues, and implications emerge that require careful thought, reflection, and discussion:

1. Why did some learners construct accurate and broad understandings while others did not? Was this difference due to student motivation, availability or quality of on-line resources, engagement with inquiry strategies, or the degree of scaffolding and support provided by the teacher?

2. Why did artifacts contain primarily factual content when students were allowed wide latitude in the selection of product formats? Why did learners demonstrate broader levels of understandings during short interviews but not when they had multiple days to develop artifacts?

3. Why did some students develop or hold to inaccurate conceptualizations when immersed in a rich informational environment that provided the potential for sense-making from many sources?

The sections below present a brief discussion of these issues and provide suggestions for educators who are attempting to utilize on-line environments like the World Wide Web for student inquiry.

Fostering In-depth Construction of Understandings

The majority of students failed to construct the type of accurate and broad understandings one would expect from seven days of on-line inquiry. However, some learners did construct and articulate understandings that went well beyond the information contained in a traditional textbook or library encyclopedia. Insights into this difference may reside in the inquiry strategies students utilized during the school year. A larger study conducted by the author (Hoffman, 1999) suggests students who obtained higher engagement with information-seeking inquiry strategies developed more robust content understandings. In addition, pedagogical practices strongly influenced student engagement with inquiry strategies. The notion of pedagogical practices influencing the construction of understanding is supported by a variety of research (Wisnudel-Spitulnik, 1998; Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991; Resnick, Levine, & Teasley, 1991). Clearly, if students are to take full advantage of on-line resources, they must be appropriately scaffolded and supported to develop strategies for posing worthwhile questions, planning and adjusting activities, generating search topics and locating useful resources, utilizing technological tools to extend inquiry efforts, assessing the usefulness and credibility of sources and information, synthesizing pertinent facts and concepts, writing and reflecting on information and processes, and creating in-depth products to represent their depth of understanding.

This study did not gather data to assess the impact of learner motivation toward information-seeking tasks, inquiry-based learning, or its impact on the construction of understanding. However, motivation may have contributed to the partial accuracy and low depth of understanding demonstrated by many learners during this study. For example, although the freedom to select individual Driving Questions was expected to increase the level of learner commitment toward the task, some students may not have been motivated to pursue detailed answers to their questions. Past research (Pintrich, Marx, and Boyle, 1993; Kruglanski, 1990; Garner, 1990) suggests that motivation may be a substantial factor associated with conceptual change -- students who did not have a strong commitment toward learning would experience difficulty constructing robust understandings. If educators intend to utilize inquiry-based learning as a vehicle for conceptual change, and have students construct broad understandings, they must (among other things) engage students with the process of inquiry and work hard to sustain high levels of motivation and commitment to task.

The quality and availability of resources could have also contributed to the lack of in-depth understandings. Perhaps students could not locate appropriate resources to support their question-asking or the sites were poorly designed and information was difficult to locate. These factors could have prevented them from constructing responses to their questions. This notion is supported somewhat by a larger study conducted by Hoffman (1999) as he describes how the quality of on-line resources (general design, content) did impact some studentsí understandings during information-seeking activities. However, he suggests that student who made use of sophisticated inquiry strategies could benefit from poor quality sites equally as well. These observations suggest a stronger relationship between inquiry strategies and content understandings rather than with resource quality. Educators should still create opportunities for students to interact with high quality information by carefully prescreening Web sites and creating hypertext links of appropriate resources (in the absence of a digital library) for learners to utilize as starting points for their inquiry.

Developing In-depth Artifacts

This study found student artifacts revealed little about the true depth of learnersí understanding. In most cases, the conceptualizations presented in posters, demonstrations, videos, presentations, and other formats displayed a simple recall of factual content. However, semi-structured interviews conducted a week following the end of a unit provided a more complete view of the content students actually acquired -- their explanations went far beyond the depth presented in artifacts. Perhaps students focused more on the appearance of products (which was the case for many artifacts) rather than on the representation of content, teachers did not make clear their expectations for artifacts, final products were not effectively critiqued for depth of understandings, or students lacked experience in creating rich artifacts extending beyond a simple presentation of facts. Although this study did not address these issues, other research provides a perspective on the difficulty of designing assessments to evaluate student understanding. Blumenfeld, Marx, Patrick, Krajcik, & Soloway (1995) describe how teachers (in inquiry-based classrooms) often asked students to produce a report or participate in a public performance, but these efforts did not require learners to synthesize information or generate "different conceptual representations." Given this perspective, educators need to provide substantial scaffolding and support to improve studentsí representation of content understandings on final products. Classroom teachers need to make clear their expectations for the depth of information required in final products, provide examples of exemplary artifacts, give constructive feedback on student work, and engage learners in constructive learning activities to extend beyond the simple recall of information.

However, this study found semi-structured interviews more productive in assessing studentsí true depth and accuracy of understanding. The interviewís design permitted the interviewer to explore detailed aspects of student understanding by rephrasing and expanding questioning to ferret out actual conceptualizations. This interview technique is supported by Bogdan & Biklen (1992) as a means of freely probing perspectives and allowing participants to "answer from their own frame of reference" rather than one structured by rigid questions. This interview method has critical implications for educators attempting to assess student understanding in inquiry-based classrooms. Although extensive interviewing of individuals is difficult with existing time constraints in classrooms, teachers need to find opportunities to engage in content specific conversations with students. This will allow teachers to obtain a true perspective on student sense-making that traditional assessments do not provide.

Mediating On-line Learning

Perhaps the most alarming insight in this study was the number of students who developed or held to inaccurate conceptualizations as a result of utilizing on-line resources. Although the information-rich environment of the World Wide Web provided ample access to a variety of resources, it did little to shape and mediate student learning. A number of factors may have contributed to these incorrect constructions of understanding: The site may have presented incorrect information, the information may have been misinterpreted by students, or students may have not extended adequate effort to thoroughly synthesize information. Original perspectives by Posner, Strike, Hewson, & Gertzog (1982) speak to the difficulty of sense-making and conceptual change. They describe how learners sometimes possess "existing concepts to deal with information" and new ideas are easily assimilated. However, more often the current concepts of students are inadequate (or incorrect) and require a "radical form" of conceptual change called accommodation. Posner et al. describe various conditions that must be fulfilled before accommodation is likely to occur: 1) There must be dissatisfaction with existing conceptions, 2) A new conception must be intelligible, 3) A new conception must appear initially plausible, 4) A new concept should suggest the possibility of a fruitful research program (further inquiry). Unfortunately, on-line environments like the World Wide Web provide little opportunity for challenging studentsí existing understandings and promoting opportunities for accommodation.

This raises a critical (perhaps the most important) issue for the continued use of technological learning tools like the World Wide Web for student content learning. Educators might assume a information-rich environment like the World Wide Web would provide ample opportunities for developing in-depth content understandings, as students are free to take advantage of the breadth of information it has to offer. However, this is far from the truth. This study observed that although some students were thoughtful in their browsing and often paused to comment on or discuss information, more prevalent were students who engaged in "surfing" rather than information-seeking -- their focus was on moving quickly through resources with the hope of locating specific answers to questions. When information was located, it was paraphrased, recorded (often out of context), and used as factual content in their artifacts.

To develop learners who are information-seekers rather than surfers, educators need to scaffold the search and synthesis strategies of students. Educators should help students learn to be more deliberate in the selection of search topics, selective in the choice of sites, thorough in the browsing of information, and thoughtful in the synthesis of content. In addition, teachers should require students to occasionally suspend their on-line activities to have a healthy conversation (partner-partner, peer-peer, peer-teacher) about the information they are encountering. Through participation in these types of conversations, educators can mediate student learning to enhance or correct in-process constructions of understanding.

This research expanded on early attempts to describe how students interact and learn from on-line learning environments like the World Wide Web. Based on this work, it is clear students can benefit from access to on-line resources when extensive support and scaffolding is provided by the teacher, but this is far from automatic. Expanded models for technology development, curriculum design, and pedagogical practices are required to successfully instantiate on-line inquiry through information-seeking in content area classrooms. Only through careful assessment of these models can the research community provide educators and policy makers with concrete guidance for utilizing technological tools like the World Wide Web in todayís schools.

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